STRATIGRAPHY OF OFFSHORE SEDIMENT
LAKE AGASSIZ–NORTH DAKOTA

by

B. Michael Arndt

REPORT OF INVESTIGATION NO. 60

NORTH DAKOTA GEOLOGICAL SURVEY

E. A. Noble, State Geologist

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ABSTRACT

Lake Agassiz occupied the Red River Valley between about 13,800 and 9,000 years ago. The Late Wisconsinan ice sheet that covered the Red River Valley retreated far enough to expose the drainage divide in northern South Dakota and south-central Minnesota sometime after 14,000 B.P. and meltwater ponded behind this divide in Richland County. Before 13,800 the ice readvanced over this area and then retreated again. As the ice margin retreated northward, deposition of the Argusville and Wylie Formations took place. Sometime before 12,800 the ice advanced again into the Red River Valley as far as Traill County; the terminus of this advance is marked by the clay rich pebble-loam of the Huot Formation, and the Falconer Formation was deposited behind the Huot. Deposition of the Argusville Formation continued in the southern part of the basin. Deposition of the Brenna Formation began when the ice margin began retreating out of the Red River Valley. About 11,000 B.P. an eastern outlet into the Lake Superior basin was opened, and Lake Agassiz dropped from the Campbell level to below the Ojata level. During the period between 11,000 B.P. and 9,900 B.P. the lake level fluctuated several times, but most of the time the lake floor was subject to erosion. A stream network similar to that of the present day developed, depositing the Poplar River Formation. About 9,900 B.P. the eastern outlets were plugged by ice and Lake Agassiz rose back to the Campbell level. The lake stood at this level for about 900 years; during this time the Sherack Formation was deposited.

The engineering properties of the Sherack Formation include low to moderate water content (17% to 56%), wide range of liquid limit (27% to 92%), and wide range of consistency index (22% to 86%). The northern part of the Brenna Formation has high water content (62% to 88%), a high liquid limit (63% to 104%), and very low penetration resistance (4 to 7 blows per foot). The southern part of the Brenna Formation and the Wylie and Argusville Formations have similar engineering properties. The range in water content (38% to 69%), liquid limit (39% to 93%), and penetration resistance (4 to 16 blows per foot) for these units are similar. The Poplar River Formation is under confined piezometric conditions, and pilings or footings in it are subject to failure. The Falconer and Huot Formations have engineering properties similar to the Sherack, Wylie, and Argusville Formations. The glacial sediments underlying the Lake Agassiz sediment provide a suitable foundation for nearly all types of construction.

INTRODUCTION

General

Between about 13,800 and 9,000 years ago glacial Lake Agassiz occupied parts of North Dakota, South Dakota, Minnesota, Saskatchewan, Manitoba, and Ontario (fig. 1). Sediment of Lake Agassiz has been recognized over an area of 200,000 square miles (Elson, 1967). This report deals with the sediment of Lake Agassiz in the Red River lowlands of North Dakota and Minnesota. This area is a bedrock lowland (fig. 2) with a regional slope to the north that has existed even through the glaciations of the Pleistocene. The present-day Red River of the North flows down the axis of the basin that was occupied by Lake Agassiz south of the International Boundary.

Purpose

Although, over the years, many geologists have worked on various aspects of Lake Agassiz geology and history, none, with the exception of Last (1974), have attempted a systematic analysis of the offshore sediment of the lake. The lack of data on these thick silt and clay deposits has retarded the development of our understanding of Lake Agassiz. Geologists have generally assumed that little

Figure 1. Extent of glacial Lake Agassiz (modified from Elson, 1967).

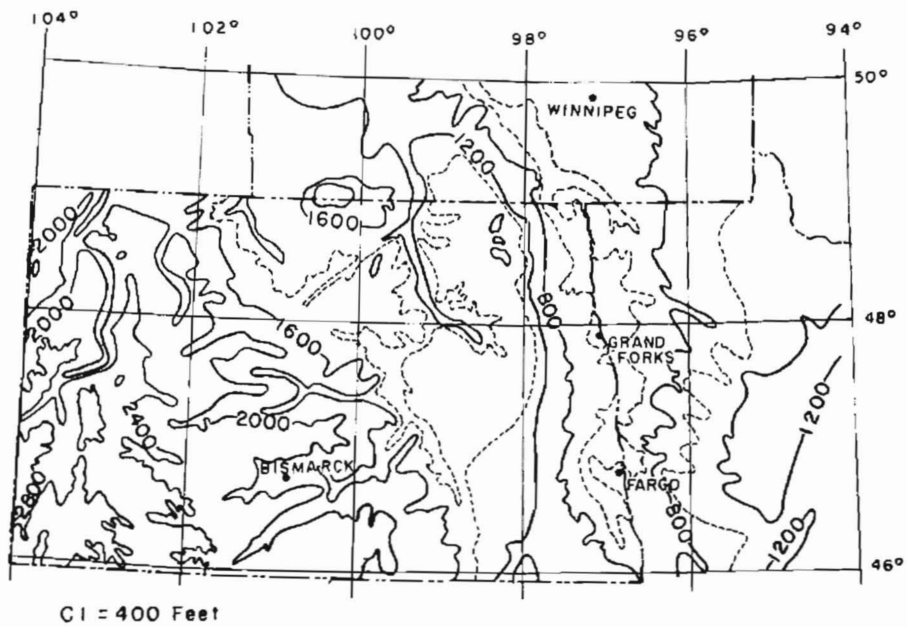

Figure 2. Preglacial topography of the Red River Valley and surrounding area.

information can be obtained from a study of the offshore sediment and have devoted most of their efforts to the shoreline and nearshore sediment.

It is shown in this report that the offshore sediment does in fact have distinct and recognizable differences. These differences are fit into a stratigraphic framework that can be related to the depositional history in the Red River basin during late Wisconsinan and early Holocene time.

Previous Studies

A historical summary of early workers who have conducted research in the Lake Agassiz basin is given by Tamplin (1967). A comprehensive summary of Lake Agassiz research is given in *Life, Land and Water*, edited by W. J. Mayer-Oakes (1967). Bulletins on the geology of each of the North Dakota counties located in the Agassiz basin have been published by the North Dakota Geological Survey (Arndt, 1974; Bluemle, 1967, 1974a; Hansen and Kume, 1970; Klausing, 1968; Baker, 1967). More recent work has been done by Harris, Moran, and Clayton (1974), Last (1974), Harris (1975), and Sackreiter (1975).

Numerous other researchers have in some way contributed to knowledge of Lake Agassiz, and those relevant to this report will be referenced in the appropriate sections.

Methodology

Test borings made by the North Dakota State Highway Department along Interstate 29 were the principal source of data for this study. Detailed information is available for 92 sites located along the interstate route from the South Dakota boundary to 29 miles south of the Manitoba border. Two or three borings were available for each of these sites. The data available for each site consists of descriptions of the material encountered and a summary of engineering test data for the sampled intervals. Engineering test data includes (1) water content for all sampled intervals, (2) standard-penetration test for at least every other sample recovered, (3) unconfined-compressive strength of selected samples, (4) dry unit weight for these same selected samples, (5) grain-size analyses of selected samples, (6) Atterberg limits for those samples upon which size analyses were performed, and (7) consistency index, which is a measure of the compressibility of a soil. Although other engineering tests were performed on some samples, they are not considered in this study. The North Dakota State Highway Department also provided cores from these borings from about 25 sites.

In addition to the interstate borings, there are about 25 other sites where engineering test borings performed by the State Highway Department were used. These sites were generally not located in the offshore part of the Agassiz basin and the data was much less complete.

Some data for Pembina County is available from test borings by the U.S. Army Corps of Engineers, primarily for dikes along the Red River and the Pembina River at Pembina, North Dakota.

During the summers of 1971, 1972, and 1973 about 150 shallow holes were drilled using the North Dakota Geological Survey truck-mounted power auger. The primary purpose of this drilling was to identify the contact between the Sherack Formation and the underlying units in the offshore region of the Lake Agassiz basin. For this reason, and because of the difficulty in obtaining samples of the Brenna and Argusville Formations using continuous-flight augers, little information was obtained under about 20 or 30 feet below the ground surface.

All data used in the preparation of this report is on file with the North Dakota Geological Survey.

ACKNOWLEDGMENTS

This study was undertaken as a part of the requirements for my doctoral dissertation. I want to thank Dr. E. A. Noble, State Geologist, who made it possible for me to pursue the study while remaining employed by the North Dakota Geological Survey. I extend my thanks to Drs. Lee Clayton, Stephen R. Moran, Walter L. Moore, and Mason Somerville for their

constructive advice and criticism during the course of the study. Stephen Moran was instrumental in suggesting the study and in helping to define the problem. My dissertation advisor, Lee Clayton, was always available to listen to my ideas and to provide insight into areas that I might have otherwise overlooked.

LITHOSTRATIGRAPHY

General

At least eight Pleistocene stratigraphic units underlie the Agassiz basin in North Dakota. Six of these units have been previously defined as formations by Harris, Moran, and Clayton (1974). One previously named formation has been subdivided into two members in this report. One new formation is named.

In standard geologic practice it is generally accepted that description begins with the lowermost, or oldest, unit and ends with the uppermost, or youngest, unit. For the nongeologist, however, I believe the discussion of units from top to bottom is easier to follow. Most engineers work with units from the top down, and because one of the principal purposes of this study is to relate the engineering properties to the geologic units, the section is described from the top down.

Before discussing the stratigraphic units it is necessary to define some terms. The grain-size terminology used in this report is based on a modified U.S. Department of Agriculture classification scheme (fig. 3). *Clay* refers to sediment in which individual particles are less than 0.005 millimetres. *Silt* refers to sediment in which the particle-size range is between 0.005 millimetres and 0.074 millimetres. *Sand* refers to sediment in which individual particles are between 0.074 millimetres and 2.0 millimetres. *Gravel* refers to sediment in which individual particles are greater than 2.0 millimetres in diameter. All references to percentage composite of the various size classes in a body of sediment are based on a total clay-silt-sand-gravel content.

In some parts of this report reference is made to structures such as I-29-102. This number is the North Dakota State Highway Deparment notation referring to highway structure 102 along Interstate Highway 29.

Appendix A summarizes the data obtained from each engineering site used for this report. A value given for any of the listed properties is a *mean* of all the values for that property at that site. In this report when a value or a range of values is given it is in fact a range of the mean values for all the sites studied.

Unit 10

Unit 10 is the surface unit over most of the Agassiz basin (pls. 1 and 2). Most generally it is silty clay or silty clay loam but contains a wide variety of grain sizes (fig. 4). In Richland County the sediment is more commonly silty or sandy. Near structure I-29-102 (T. 133 N., R. 50 W., sec. 22SW¼NW¼) the surface sediment is loamy sand. South of structure I-29-110 (T. 131 N., R. 49 W., sec. 28SE¼SW¼SW¼) unit 10 ranges from loamy sand to sand. The sediment of this unit is massive or has a granular structure and in some places is weakly laminated. Organic material is a common constituent of this sediment. The thickness of this unit ranges from less than 1 foot to more than 25 feet. It is thickest near streams.

Most of the silt and clay part of this unit is alluvium. This unit also includes topsoil, nearshore and offshore lacustrine sediments, and fill.

Sherack Formation

The Sherack Formation was defined on the basis of subsurface borings near Oslo, Minnesota, and Grand Forks, North Dakota (Harris and others, 1974). In the center part of the basin, north of Thompson in southern Grand Forks County, the Sherack Formation contains primarily brown to light gray laminated silty clay. The silt content ranges from 33 to 56 percent, and the clay content ranges from 40 to 63 percent (fig. 5). The well defined laminations are generally a few millimetres thick. In some places the silty parts of the laminations are several tens of millimetres thick.

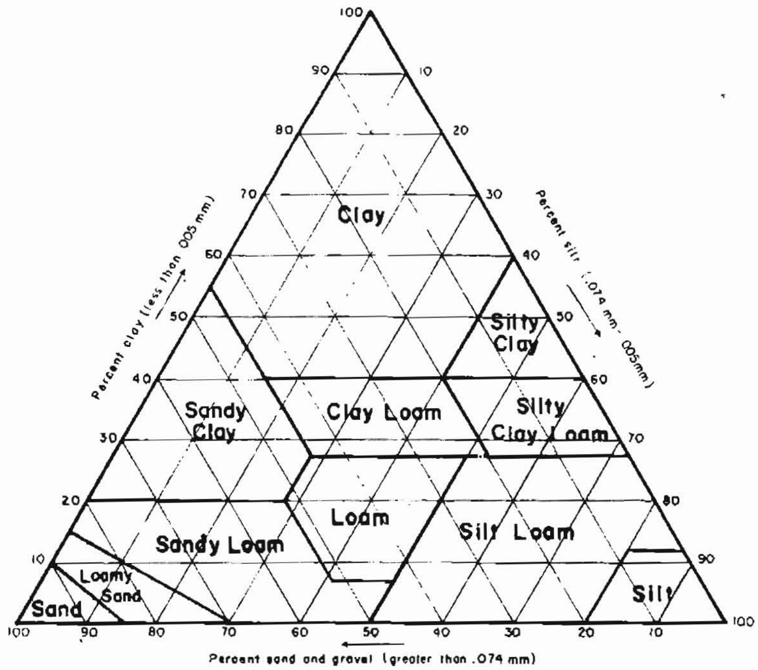

Figure 3. Modified U.S. Department of Agriculture grain-size classification chart.

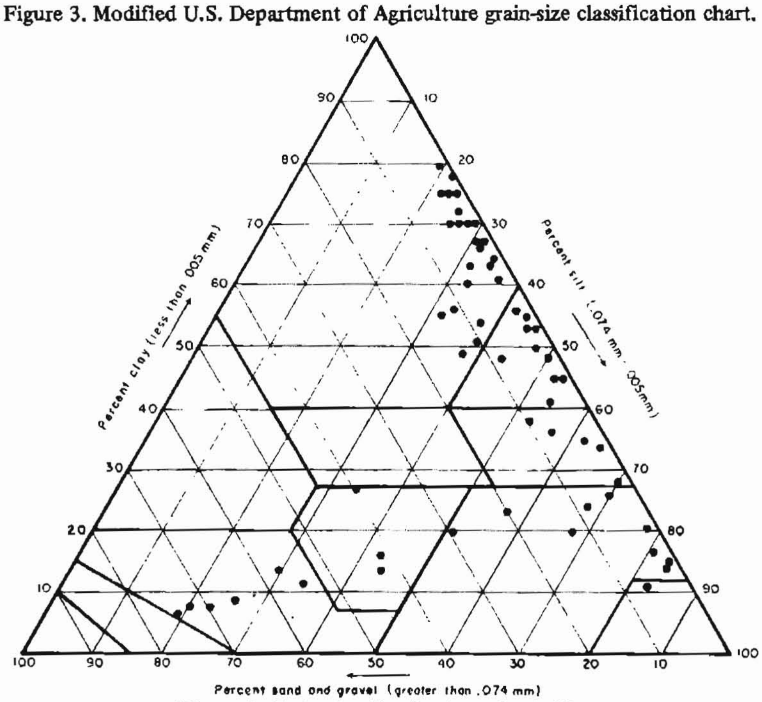

Figure 4. Grain-size distribution of unit 10.

From Thompson to Hillsboro, the silt content in the Sherack Formation becomes considerably greater (fig. 5, pls. 1 and 2). In places, the silt content may exceed 80 percent. The clay content in this area is substantially less than either north of Thompson or south of Hillsboro. The laminations here are also well defined.

South from Hillsboro (south of the Huot Formation) to about 5 miles north of Hankinson the silt content is substantially reduced, and clay becomes the dominant size fraction (fig. 5). The clay content generally ranges from 60 to 90 percent. The color of the sediment is light brownish gray (10YR 6/2, Munsell soil color designation) where unoxidized and gray (5Y 6/1) where oxidized. The laminations, which are well defined further north, are difficult to recognize in the area between

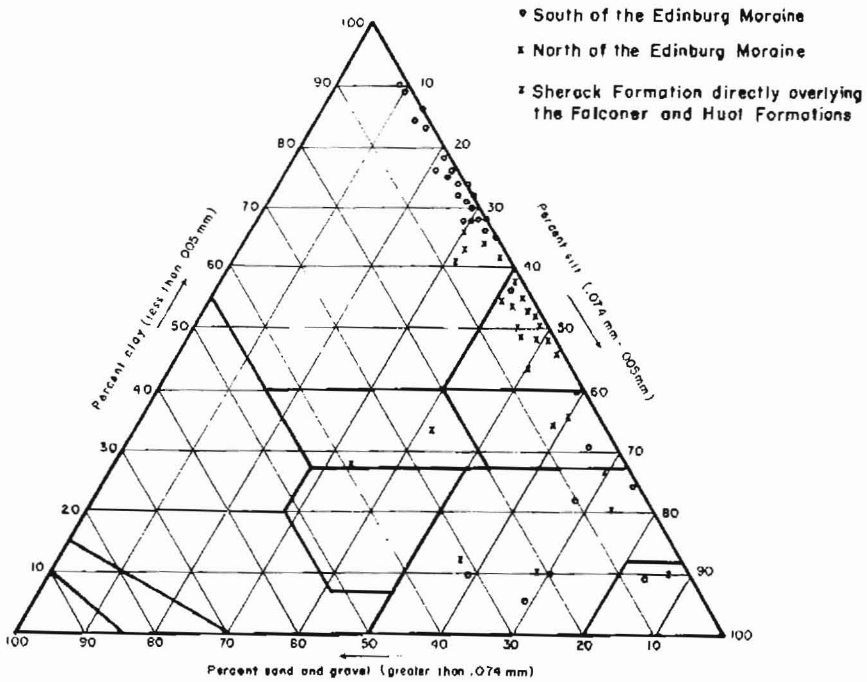

Figure 5. Grain-size distribution of the Sherack Formation.

Hillsboro and Colfax. In this part of the basin the contact between the Sherack Formation and the underlying Brenna Formation is gradational and difficult to recognize.

The Sherack Formation unconformably overlies the Brenna, Falconer, Huot, and Argusville Formations and the Harwood Member of the Poplar River Formation. It conformably overlies the West Fargo Member of the Poplar River Formation. South of about Hankinson, the Sherack Formation unconformably overlies Unit B (pl. 2).

The Sherack Formation is easily recognized by its laminations and stratigraphic position. Only south of about Hillsboro, where the Sherack Formation overlies the Brenna Formation, is its lower boundary difficult to recognize. In this area, engineering-test data, especially water content, can be used to differentiate the two formations (see table 2 in section dealing with engineering applications). Water content of the sediments in the Sherack Formation are consistently lower, by about 10%, than in the underlying Brenna Formation.

The Sherack Formation is equivalent to unit 3 of Last (1974) in southern Manitoba, and unit 2 of Moran (1972) in Grand Forks County.

The sediment of the Sherack Formation was deposited, for the most part, in the offshore environment of Lake Agassiz. In southern Richland County, the sediment of the Sherack Formation grades into sand deposited in the near-shore environment.

Poplar River Formation

The Poplar River Formation consists largely of fine- to coarse-grained sand and minor amounts of gravel (Harris and others, 1974). Where sand and gravel of the Poplar River Formation is present in the center of the Agassiz basin it is nearly everywhere associated with a distinctive clayey unit. Therefore, I propose to divide the Poplar River Formation into two members: (1) West Fargo Member and (2) Harwood Member. Harris and others (1974) defined an outcrop along the Red Lake River in the Red Lake Falls, Minnesota, area as the type section for the Poplar River Formation. They recognized that this formation occurs extensively in the Fargo area where both members are well developed.

West Fargo Member (New)

Source of name: The town of West Fargo, Cass County, North Dakota.

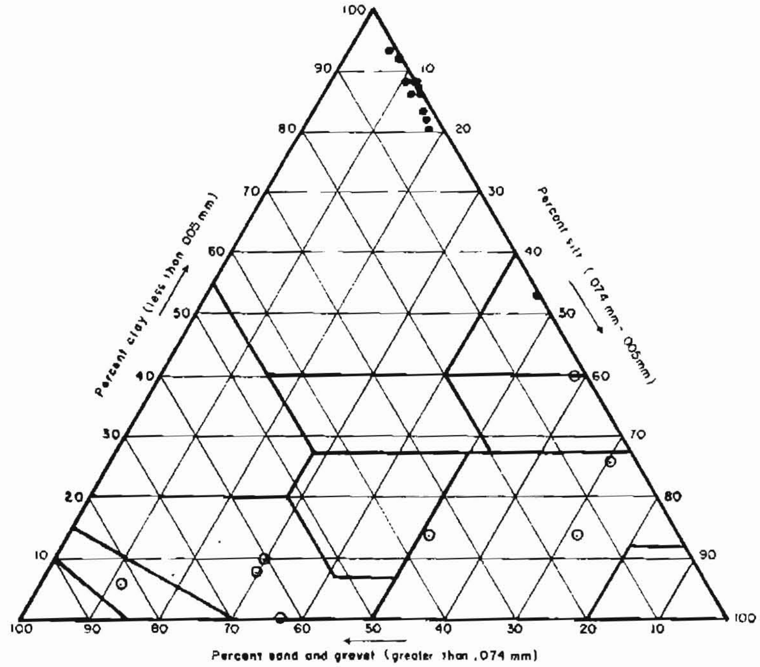

Figure 6. Grain-size distribution of the Poplar River Formation.

Type area: Fargo, North Dakota area.

Type section: Composite of boring numbers 1, 2, and 3, F-2 Dormitory, Moorhead State College, Moorhead, Minnesota, T. 139 N., R. 48 W., sec. 8SE¼NE¼SE¼ (Appendix C).

Reference sections: The West Fargo Member occurs extensively in the Fargo area but no reference sections are designated at this time.

The West Fargo Member is that part of the Poplar River Formation included in the original definition. Near Fargo, the West Fargo Member is predominantly composed of sand. Where it is present in Traill, Walsh, and Pembina Counties, it is composed mostly of silt and very fine sand (fig. 6). Testhole samples commonly show it to have well defined laminations. Both large-scale and small-scale crossbedding has been observed (Harris and others, 1974). Shells of clams, snails, and mussels have been observed by Moran and others (1971). Very commonly, peat, wood, and other organic fragments are found in the West Fargo Member. Peat, as much as 3 feet thick, was obtained from a testhole drilled in T. 148 N., R. 49 W., sec. 33SE¼SE¼SW¼ in Traill County. In the silty parts of this member, organic zones form conspicuous laminae and in places are as much as 30 millimetres thick.

The West Fargo Member unconformably overlies the Brenna Formation, and the contact between these two units is abrupt. The West Fargo Member conformably overlies the Harwood Member of the Poplar River Formation and has a distinct boundary with it. The West Fargo Member is overlain by the Sherack Formation and the contact between the two is gradational. The boundary is placed where sand ceases to be a significant constituent and clay beds are abundant (Harris and others, 1974).

The West Fargo Member is easily distinguished by its lithologic characteristics, presence of organic layers, and stratigraphic position.

The presence of the West Fargo Member in the subsurface is commonly indicated on the surface by the presence of a low ridge that can generally be traced along the distance of the subcrop of this unit (fig. 7).

Some of these *compaction* ridges have been previously identified as the Sheyenne, West Fargo, Fargo, and Maple Ridges in Cass County (Klausing, 1968), Kelso Ridge in Traill County (Bluemle, 1967), and the Horgan Ridge in Pembina County. Appendix C describes how these compaction ridges form.

The West Fargo Member consists of

fluvial-channel sediment and near-channel overbank sediment.

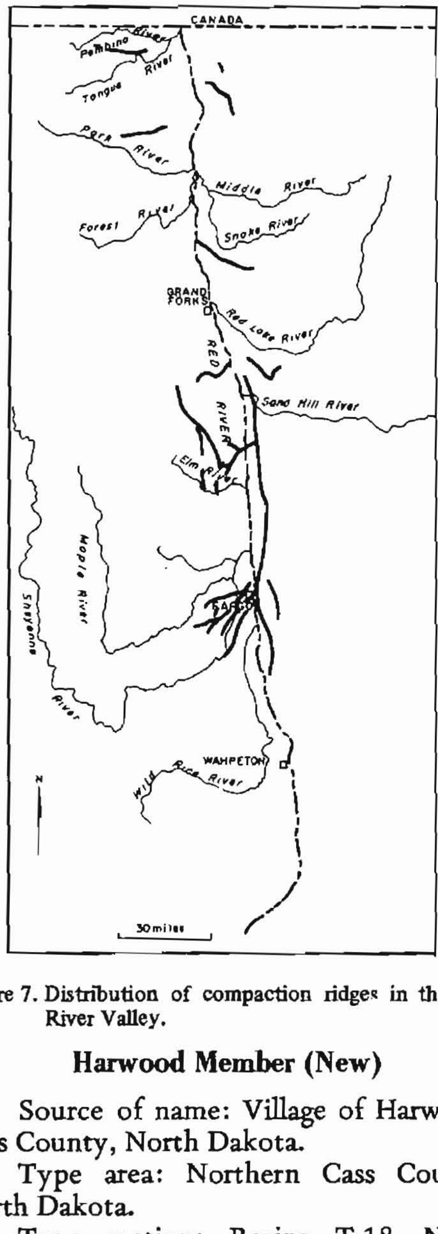

Figure 7. Distribution of compaction ridges in the Red River Valley.

Harwood Member (New)

Source of name: Village of Harwood, Cass County, North Dakota.

Type area: Northern Cass County, North Dakota.

Type section: Boring T-18, North Dakota Geological Survey testhole, T. 147 N., R. 49 W., sec. 11SW¼SW¼SW¼.

Reference section: The Harwood Member is found extensively in the Cass County, North Dakota, area but no reference sections are designated at this time.

The Harwood Member is composed mostly of clay (fig. 6). It has a mealy structure (like cooked oatmeal mush) and color ranges from gray (5Y 5/1 and 4/1) to a mottled dark grayish brown (2.5Y 4/2). It is usually not more than 6 feet thick. It is stiff and brittle and is difficult to break when fresh. It is noticeably more difficult to drill through this member than either the overlying or underlying units. Standard-penetration tests performed in conjunction with engineering-test boring range between 8 and 18 blows per foot.

The Harwood Member is overlain by the Sherack Formation and the West Fargo Member of the Poplar River Formation and overlies the Brenna Formation (pls. 1 and 2).

The Harwood Member is easily recognized by its distinct mealy structure, stratigraphic position, and resistance to penetration.

Last (1974) includes the Harwood Member in the upper part of his unit 2. Rominger and Rutledge (1952) include it in their unit 4. They interpreted the sediment of this unit to be of lacustrine origin that was subject to dessication during a low-water phase of Lake Agassiz. The limited distribution and common association with the West Fargo Member leads me to conclude that their interpretation is incorrect. The Harwood Member commonly occurs in association with the fluvial-channel sediment of the West Fargo Member. The structure of the Harwood Member is similar to that of alluvium associated with present-day rivers in the Red River Valley. For these reasons, I believe the Harwood Member to be fluvial-overbank sediment.

Brenna Formation

The Brenna Formation is composed mostly of clay and was defined from subsurface borings near Grand Forks (Harris and others, 1974). It was originally only recognized as far south as northern Traill County. In this report, the Brenna Formation is recognized to just south of the Cass-Richland County line. The clay content of the Brenna Formation ranges from 70 to 95 percent north of the Huot Formation and from 58 to 95 percent south of the Huot Formation (pls. 3). The sand content nearly everywhere is generally less than 1 percent (fig. 8). South of the Huot Formation, the color of the Brenna Formation ranges from grayish brown

(2.5Y 5/2) to dark gray (5Y 4/1). North of the Huot Formation, it is generally between gray and very dark gray (5Y 6/1 and 5Y 3/1). The Brenna Formation is generally unbedded or obscurely laminated, but in places contains some well laminated zones. Soft, white and pink calcareous nodules and fragments are common. North of the Huot Formation these nodules and fragments are abundant, and their presence decreases markedly south of the Huot Formation. Slickensides are commonly seen on fractures in freshly broken moist samples; engineers commonly call the Brenna Formation the "Slickensided Clay."

The Brenna Formation is unconformably overlain by the Sherack Formation and Poplar River Formation and conformably overlies Falconer and Argusville Formations. Where the Brenna Formation overlies the Falconer Formation the contact is gradational and is commonly marked by a transition zone marked by an increase in sand content and pebble-loam inclusions.

The Brenna Formation is recognized by its large amount of clay, lack of structure, and the slickensided fracture surfaces. North of the Huot Formation this formation is very soft. Standard-penetration tests are in some places less than one blow per foot. The Brenna Formation is easily distinguished from all other units except where the Sherack Formation overlies it south of the Huot Formation. The similar textural composition (pl. 3) and poorly developed laminations in the Sherack Formation make it difficult to pick the boundary.

The Brenna Formation is equivalent to unit 3 of Moran (1972), units 1, 2, and 3 of Rominger and Rutledge (1952), and units 1 and 2 of Last (1974).

The Brenna Formation is sediment that was deposited in Lake Agassiz. The somewhat coarser grained material recognized near the base includes some mud flow deposits.

Falconer Formation

The Falconer Formation is defined as consisting of silty, clayey pebble-loam. This pebble-loam makes up the bulk of the Falconer Formation, but the Falconer also contains a few beds of sand or gravel and some contorted silt beds. The data used for this report show that clay content of this formation ranges from 11 to 56 percent and silt content ranges from 28 to 65 percent (fig. 9). Color of the Falconer Formation is generally light gray (5Y 6/1). It has no apparent structure or bedding.

The Falconer Formation is unconformably overlain by the Sherack Formation and conformably overlain by the Brenna Formation. It conformably overlies the Wylie Formation, and the contact between the two appears to be gradational (Harris and others, 1974). Where the Wylie Formation is not present, the Falconer Formation rests unconformably on older pebble-loam unit A (unit A, pls. 1 and 2), that is probably equivalent to the Dahlen or Red Lake Falls Formations (Moran, 1972).

The Falconer Formation is lithologically distinct and is easily distinguished from both overlying and underlying units. It is less clayey than the Sherack, Brenna, or Wylie Formations. Pebbles are common in this formation but are absent or rare in the underlying and overlying units. Where the Falconer Formation grades into the Huot Formation, the boundary is placed where sand content is 10 percent. The Falconer contains more than 10 percent sand and the Huot contains less than 10 percent sand.

The Falconer Formation has been correlated with the Marchand Formation in Manitoba (Moran and others, in press).

The pebble-loam of the Falconer Formation is glacial sediment deposited by a minor readvance of a generally retreating Late Wisconsinan glacier in the Agassiz basin.

Huot Formation

The Huot Formation was defined in outcrops along the Red Lake River near Huot, Minnesota (Harris and others, 1974). It contains unbedded slightly pebbly clay-loam. Its color in outcrop is gray (5Y 5/1, dry) to grayish brown (2.5Y 3/2, wet). In the subsurface, in Traill County, it is

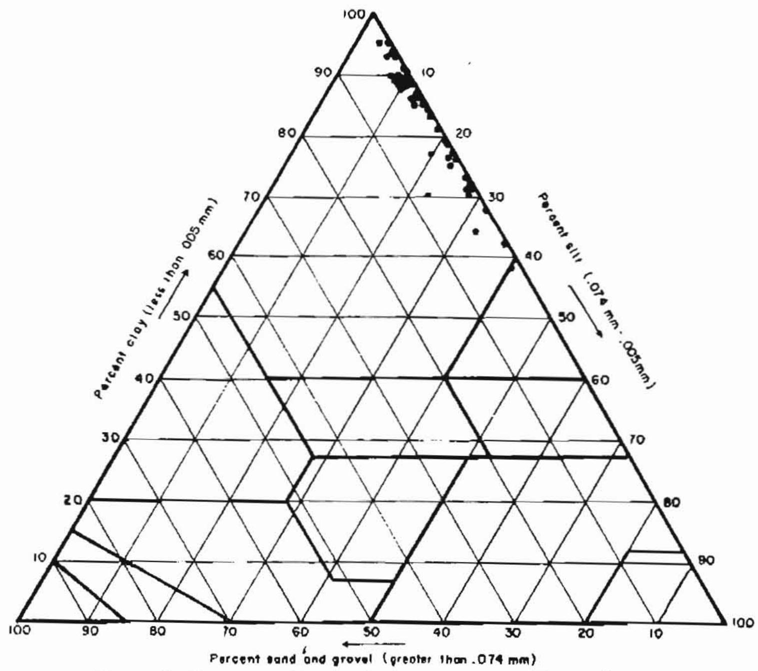

Figure 8. Grain-size distribution of the Brenna Formation.

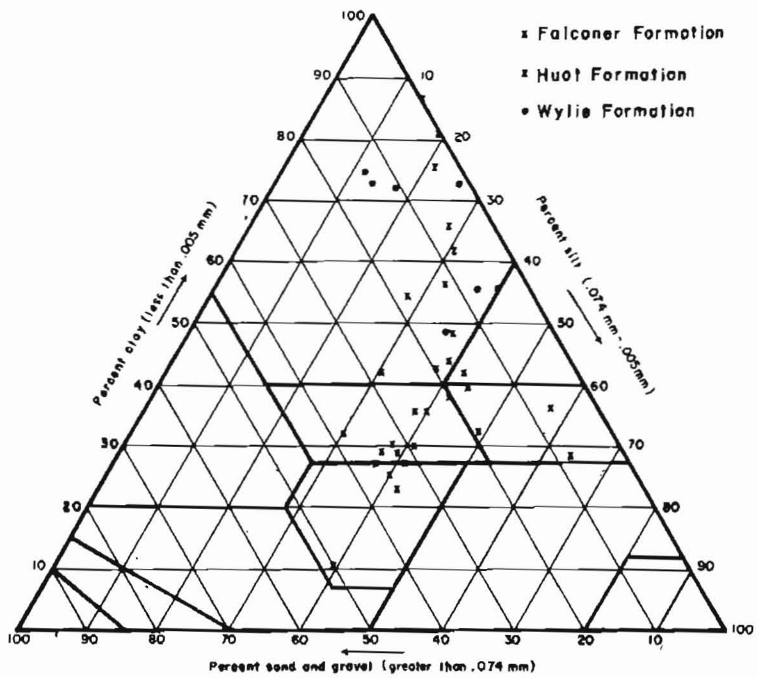

Figure 9. Grain-size distribution of the Falconer, Huot, and Wylie Formations.

generally gray (5Y 5/1) to dark gray (5Y 4/1). In the center of the basin it has a clay content between about 60 and 85 percent (fig. 9). Because it contains a large amount of clay it tends to have slickensided surfaces like the clay of the Brenna Formation.

The Huot Formation is unconformably overlain by the Sherack Formation and unconformably underlain by unit A (pl. 2). The Brenna Formation conformably overlies it. It is laterally gradational with the Falconer Formation to the north and the Argusville Formation to the south.

The Huot Formation is characterized by a large amount of clay, the lack of bedding, and the presence of pebbles. Where the Huot Formation grades into the Argusville Formation the boundary is placed where sand content is 5 percent and where pebble content is 0.1 percent.

The Huot Formation is glacial sediment that flowed into Lake Agassiz off the front of the ice that deposited the pebble-loam of the Falconer Formation.

Wylie Formation

The Wylie Formation is defined on the basis of outcrops along the Red Lake River near Wylie, Minnesota. In its type section, the Wylie Formation consists of olive gray (5Y 5/2) to dark gray (5Y 4/1), laminated silt and clay. The laminations range in thickness from a few millimetres to 10 millimetres (Harris and others, 1974). In the center of the basin between northern Traill County and northern Walsh County, the Wylie Formation is a discontinuous unit made up mostly of clay (fig. 9). The Wylie Formation in this part of the basin has no apparent structure and has the same slickensided fracture surfaces as the Brenna Formation.

The Wylie Formation is conformably overlain by the Falconer Formation, and the contact between the two is diffuse and gradational. This formation overlies unit A (pls. 1 and 2) which is probably the Red Lake Falls Formation (Moran, 1975).

The Wylie Formation is lithologically distinct from the Falconer Formation and the underlying unit A. The Wylie Formation consists mostly of clay, and the Falconer Formation and unit A contain primarily pebble-loam. The nature of the contact with the Falconer Formation is gradational, and it is difficult to determine the boundary. The boundary with the lower unit is also gradational.

The Wylie Formation is offshore lacustrine sediment deposited in Lake Agassiz prior to the advance of ice that deposited the Falconer and Huot Formations.

Argusville Formation (New)

Source of Name: Village of Argusville, Cass County, North Dakota.

Type Area: Southern Traill County and northern Cass County, North Dakota.

Type Section: Boring number 2 of Interstate 29 structure 89, Rose Coulee Bridge, Cass County, North Dakota, T. 139 N., R. 49 W., sec. 26SW¼SW¼SW¼.

Reference Sections: Boring number 1 of Interstate 29 structure 89; boring numbers 1, 2, 3 of Interstate 29 structure 68, interchange south of Grandin, Cass County, North Dakota, T. 143 N., R. 50 W., sec. 15SE¼NE¼SW¼; boring number 1 of Interstate 29 structure 91, St. Benedict Interchange at St. Benedict, Cass County, North Dakota, T. 138 N., R. 49 W., sec. 35SW¼SW¼SE¼; composite boring numbers 1, 2, 3 of Interstate 29 structure 105, Mooreton Interchange at Mooreton, Richland County, North Dakota, T. 133 N., R. 49 W., sec. 9NE¼SW¼SW¼.

The Argusville Formation is composed mostly of clay (fig. 10). Clay content ranges from 56 to 84 percent and sand content ranges from 2 to 6 percent. Its color ranges from gray (5Y 6/1) to dark gray (5Y 4/1). It is generally unbedded, but darker colored stringers are common, giving a marbled appearance that may be mistaken for laminations. Calcareous silt balls and pebble-loam balls, generally less than 10 millimetres in diameter, are common throughout the unit.

The Argusville Formation is overlain by the Brenna Formation except in Richland County where it is directly overlain by the Sherack Formation. It overlies Units A and B (pl. 2). The Argusville Formation is gradational with the Huot Formation, and the boundary is placed where the sand content is 5 percent and 0.1 percent.

The Argusville Formation is made up of offshore lacustrine sediment. It was deposited in the Agassiz basin as the Late Wisconsinan glacier retreated out of the area prior to the readvance that was responsible for the deposition of the Falconer and Huot Formations.

Units A, B, C, D

Unit A nearly everywhere underlies sediments associated with Lake Agassiz (pl. 2). It is composed mostly of gray to dark gray, silty, sandy pebble-loam. In Traill County, the upper part of unit A is made up of a sand and gravel body that has been

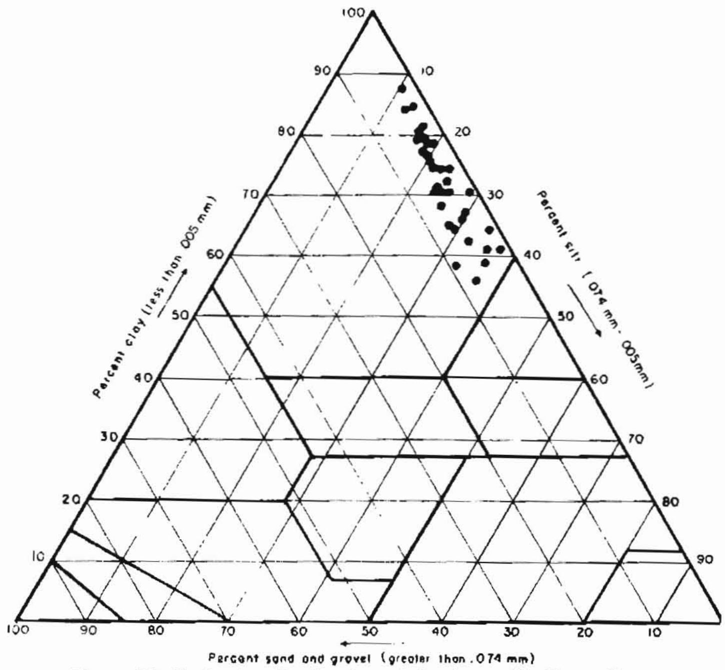

Figure 10. Grain-size distribution of the Argusville Formation.

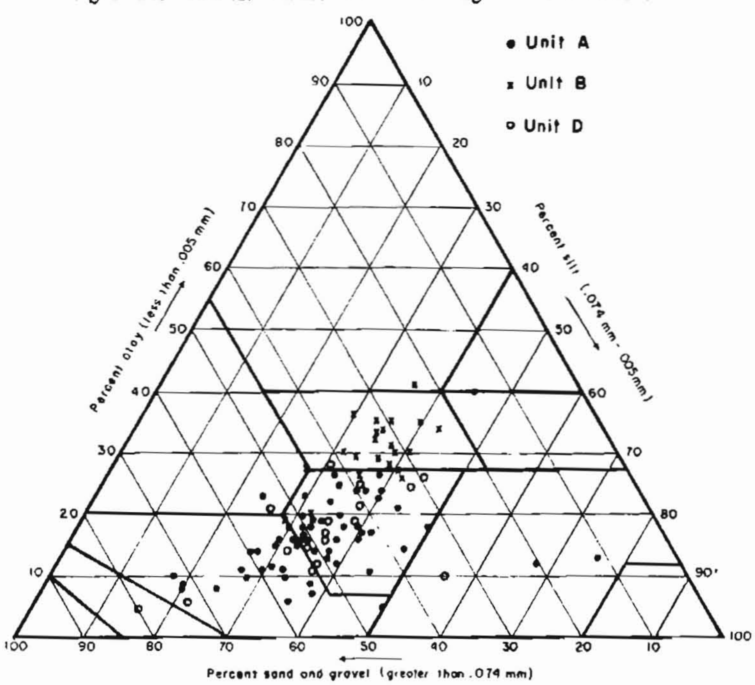

Figure 11. Grain-size distribution of unit A, unit B, and unit D.

called the Hillsboro Aquifer (Jensen and Klausing, 1971).

Unit B is made up primarily of gray to dark gray, silty pebble-loam. It contains more clay than unit A (fig. 11). This unit underlies sediment of Lake Agassiz in Richland County (pl. 2).

Unit C is composed mostly of silty clay and underlies unit B in Richland County. The clay is generally unbedded to weakly laminated and the laminations are commonly contorted. This unit has incorporated within it abundant pebble-loam inclusions.

Unit D is a gray, sandy, silty pebble-loam that underlies unit C (pl. 2). It also contains a significant amount of sand and gravel. In the area around Colfax in northern Richland County this sand and gravel has been identified as the Colfax

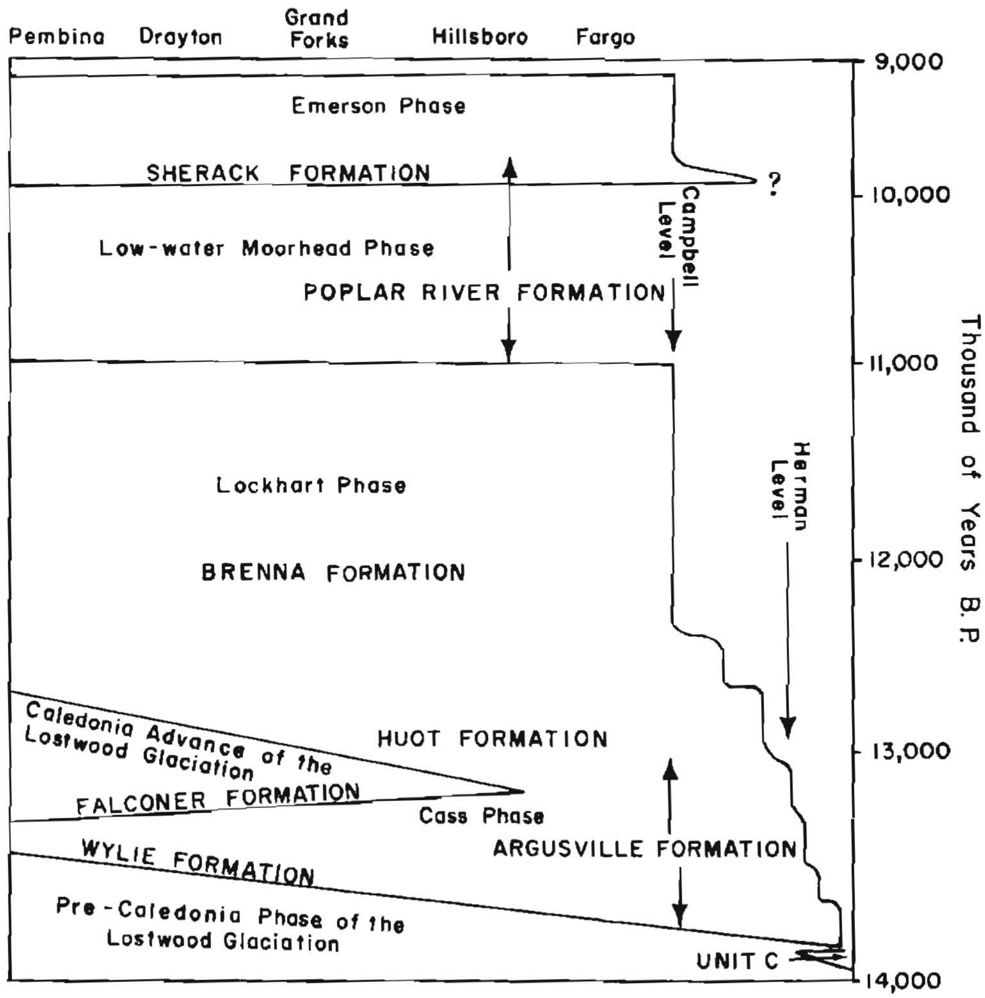

Figure 12. Time-distance diagram showing events in the Lake Agassiz basin of North Dakota.

Aquifer (Baker and Paulson, 1967).

Unit A, unit B, and unit D are glacial sediment deposited by ice that occupied the Agassiz basin during the Late Wisconsinan. Unit C is offshore lacustrine sediment deposited in the Agassiz basin following a minor glacial retreat during the Late Wisconsinan.

It is not known whether unit B or unit D is stratigraphically equivalent to unit A. Grain-size data (fig. 11) and engineering data (pl. 3) suggest that unit A is equivalent to unit D. This means that unit B and the underlying clay of unit C were deposited by a sequence of events similar to that for the Falconer and Wylie Formations.

EVENT STRATIGRAPHY

Pre-Lostwood Glaciation

All glacial, glacio-fluvial, and glacio-lacustrine sediment below the Red Lake Falls Formation (?) or its equivalent in the Agassiz basin is included in the pre-Lostwood Glaciation.

Lostwood Glaciation (Figure 12)

The Red River Valley was completely covered with ice for the last time during

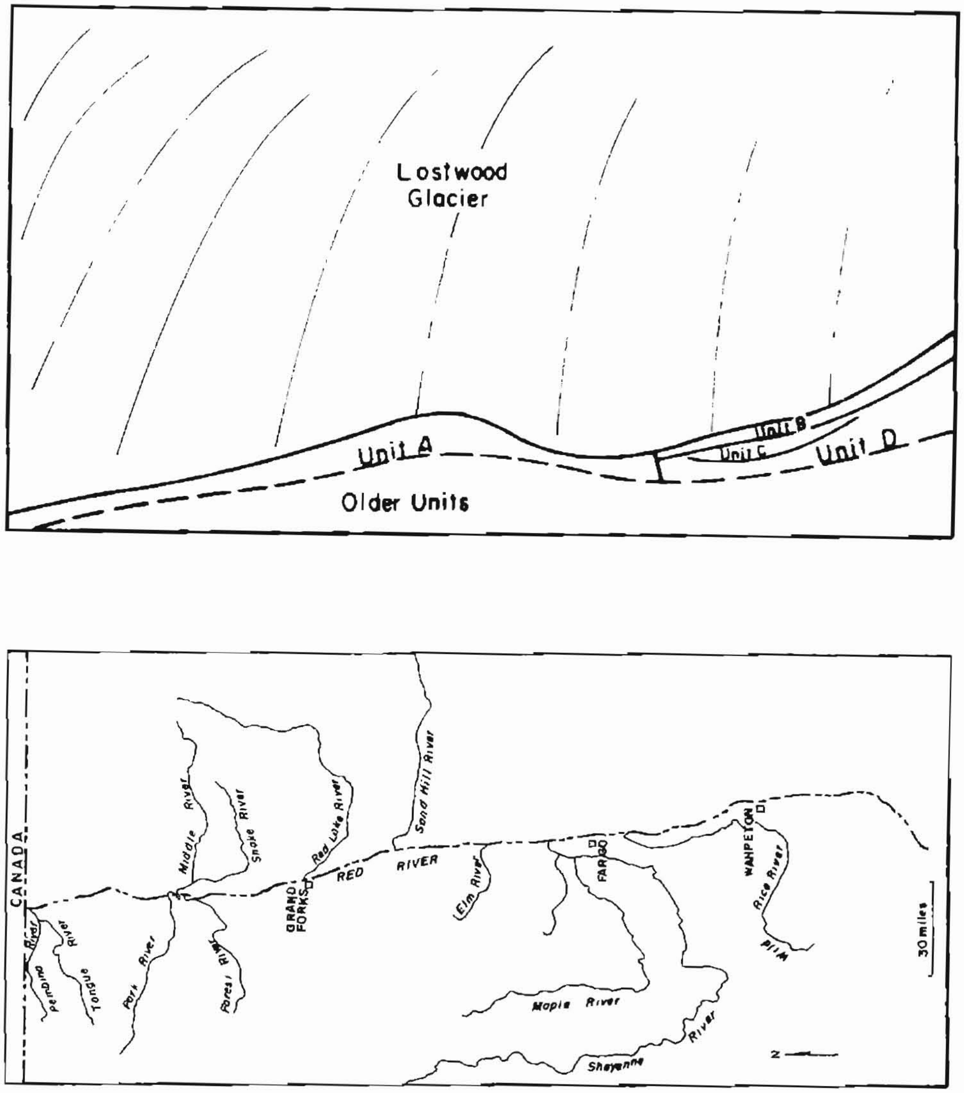

Figure 13. North-south cross section and map view of the Lostwood Glaciation in the Lake Agassiz basin.

the Lostwood Glaciation about 14,000 years ago when the Des Moines lobe was still active in Iowa. Sometime after 14,000 B.P. (Before Present) the ice margin had retreated sufficiently to expose the drainage divide in northern South Dakota and south-central Minnesota. Unit C was deposited in the meltwater that was ponded behind this drainage divide. Sometime after the deposition of unit C the ice readvanced southward (fig. 13). By about 13,500 B.P. the ice had again retreated far enough to expose the drainage divide. The meltwater ponded behind this divide marks the beginning of the first high-water stage of Lake Agassiz, which is named the Cass Phase.

Cass Phase

During the Cass Phase, Lake Agassiz was largely surrounded by stagnant ice (fig. 14). Evidence of strandlines on this ice was first recognized by Bluemle (1974b); they are well above the Herman level, considered since Upham (1895) to be the highest level of Lake Agassiz. Moran and Clayton (1972) reported on the possibility of the existence of three lakes in the Agassiz basin that became Lake Agassiz when they coalesced during the Cass Phase.

In the southern part of the basin, the

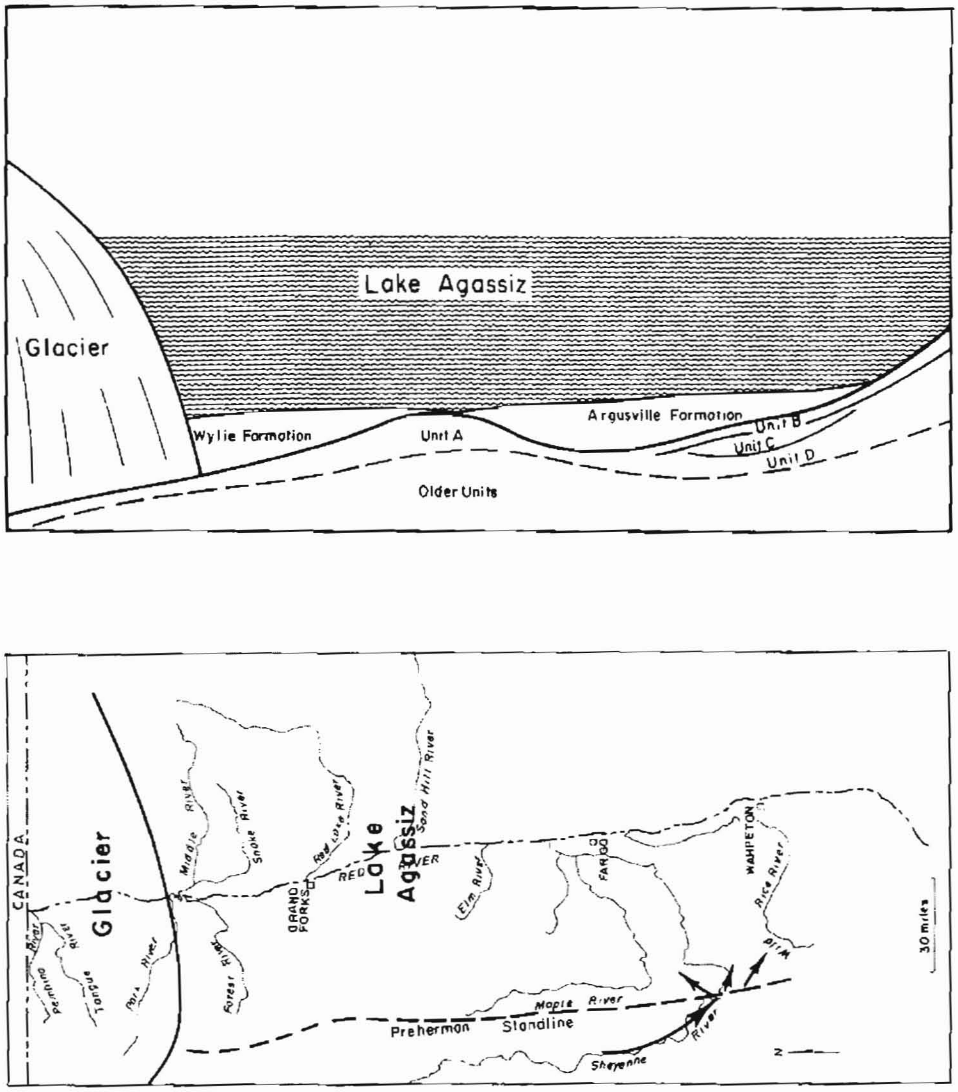

Figure 14. North-south cross section and map view of the Cass Phase in the Lake Agassiz basin.

lower part of the Argusville Formation was deposited as the ice retreated. The Wylie Formation is the result of the same depositional event. The Sheyenne River was the primary source of sediment in the southern part of the lake basin. Much of the sediment supplied by the Sheyenne River was derived from the Pierre Formation. The river cut a deep trench into the shale of this formation, which supplied large amounts of fine-grained sediment to the southern part of this basin. Where the Sheyenne River entered the lake, the Sheyenne Delta was formed. As the ice retreated northward in the Red River Valley, rivers flowing between the ice in the Valley and the higher land to the west added to the sediment input into the lake.

How far the ice retreated during the Cass Phase is not known, but it was out of North Dakota because the Wylie Formation is recognized in southeastern Manitoba (Moran and others, in press). Sometime before 12,800, the retreat of the ice margin was halted, and the ice began to readvance up the Red River Valley. This readvance marks the end of the Cass Phase.

Caledonia Advance

As the ice advanced up the Red River Valley it eroded the previously deposited

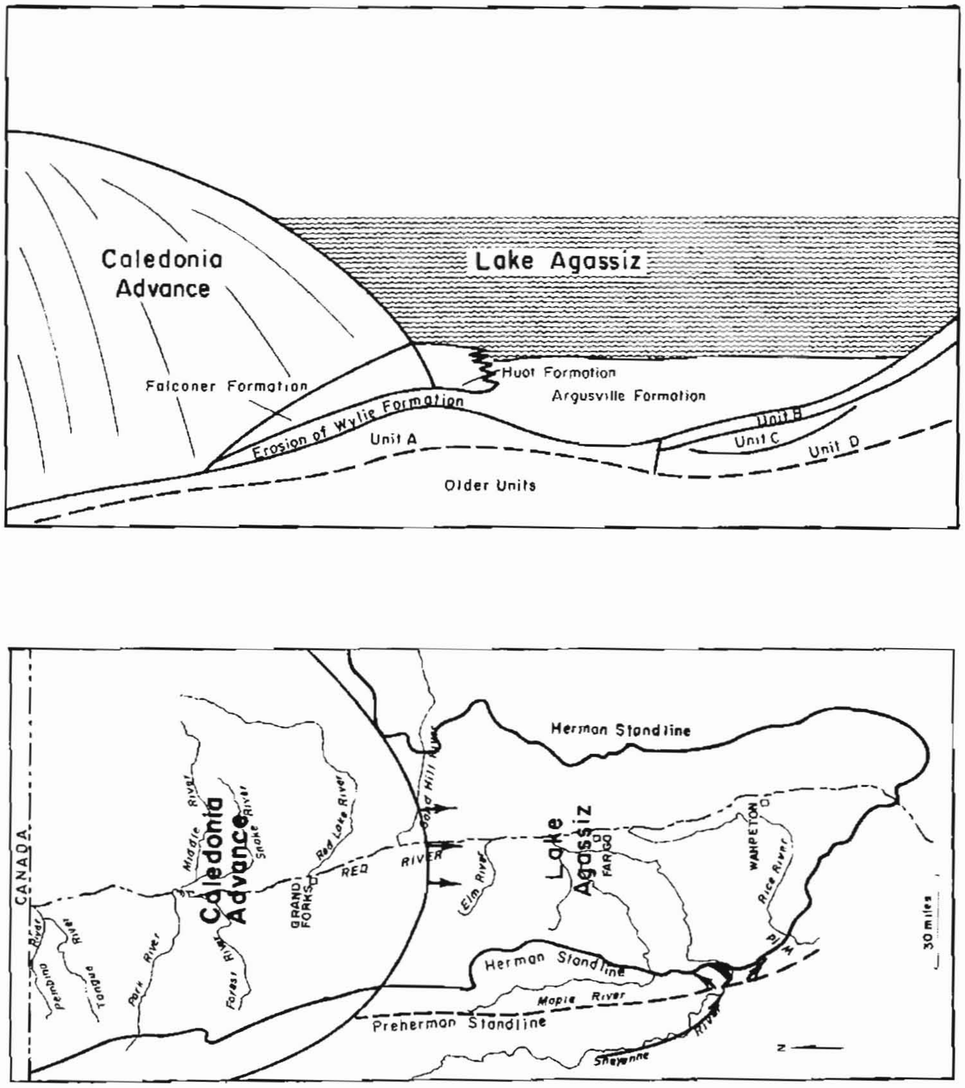

Figure 15. North-south cross section and map view of the Caledonia Advance in the Lake Agassiz basin.

lacustrine sediment. In some places the Wylie Formation was completely removed (pls. 1 and 2). The terminus of the Caledonia Advance is marked by the Edinburg Moraine that, in Traill County, is made up of the Huot Formation. Deposition of the upper part of the Argusville Formation continued during the Caledonia Advance (fig. 15).

Just when the Caledonia Advance reached its maximum extent is not known, but the next high-water phase of Lake Agassiz is considered to have begun at this time.

Lockhart Phase

The Lockhart Phase of Lake Agassiz began in the southern part of the basin and the lake spread northward as the ice front retreated. Deposition of the Brenna Formation began during this phase (fig. 16). The major sediment source for the lake was the Pierre Formation.

Formation of the Sheyenne Delta, which began during the Cass Phase, continued into the Lockhart Phase. The Galesburg, Elk Valley, and Pembina Deltas were formed along the Pembina

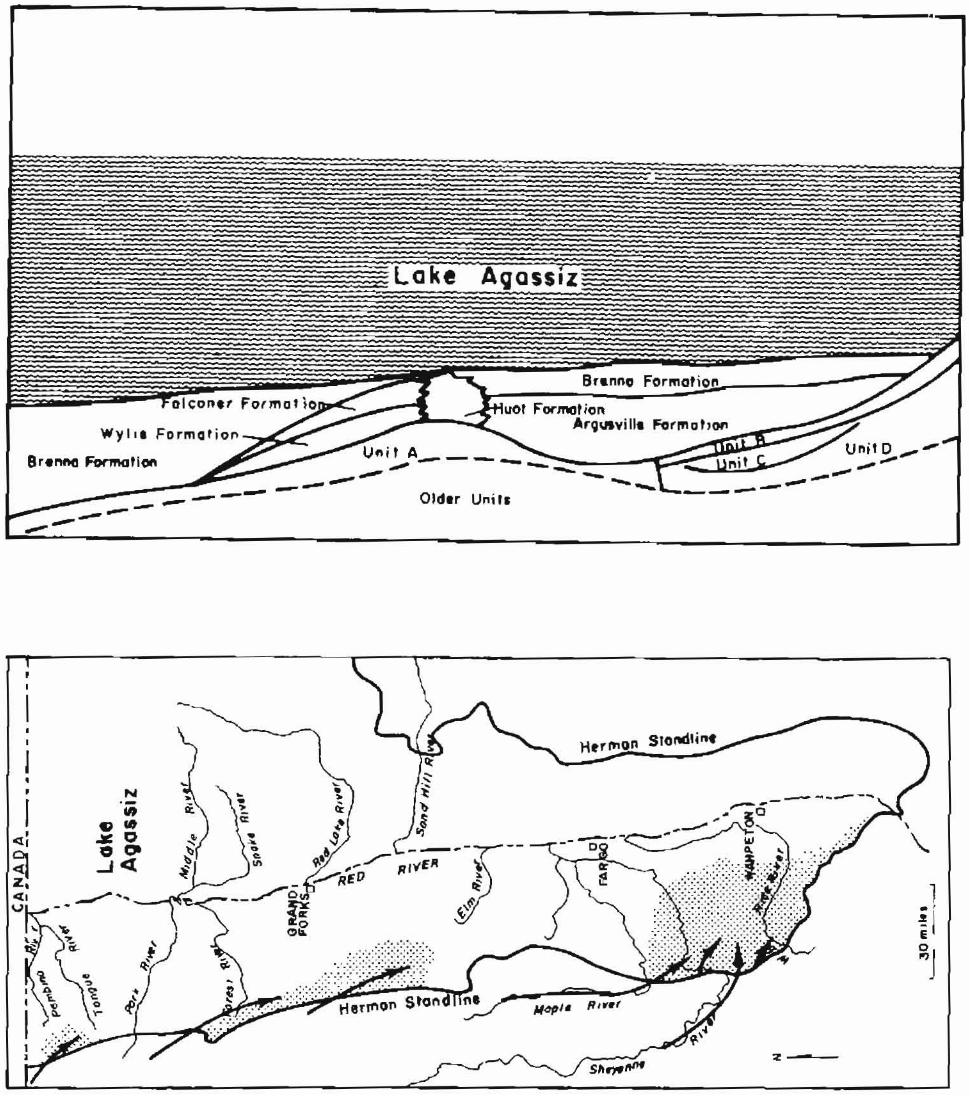

Figure 16. North-south cross section and map view of the Lockhart Phase in the Lake Agassiz basin.

Escarpment where southeastward flowing rivers entered Lake Agassiz.

During the Lockhart Phase the Herman level was established. This level is above the level of the drainage divide in northern South Dakota and south-central Minnesota, so drainage of the lake was, as during the Cass Phase, southward through the Minnesota River Valley.

Downcutting of this southern outlet continued until the Campbell level was attained. The lake stood at this level until about 11,000 B.P. when an eastern drainage outlet was opened into the Lake Superior basin (Elson, 1967). This drainage outlet to the east resulted in the lowering of Lake Agassiz in the Red River Valley.

Moorhead Phase

The opening of the eastern outlet and resulting lowering of Lake Agassiz marks the end of the Lockhart Phase and the beginning of the low-water Moorhead Phase (fig. 17). During the Moorhead Phase there were several lake fluctuations. Moran and others (1972) describe the history of events occurring in the Agassiz basin during the Moorhead Phase as follows: (1) By 10,900 B.P. the lake stood at the Ojata level; (2) The eastern outlet was again plugged by ice, and by 10,700 B.P. Lake Agassiz had

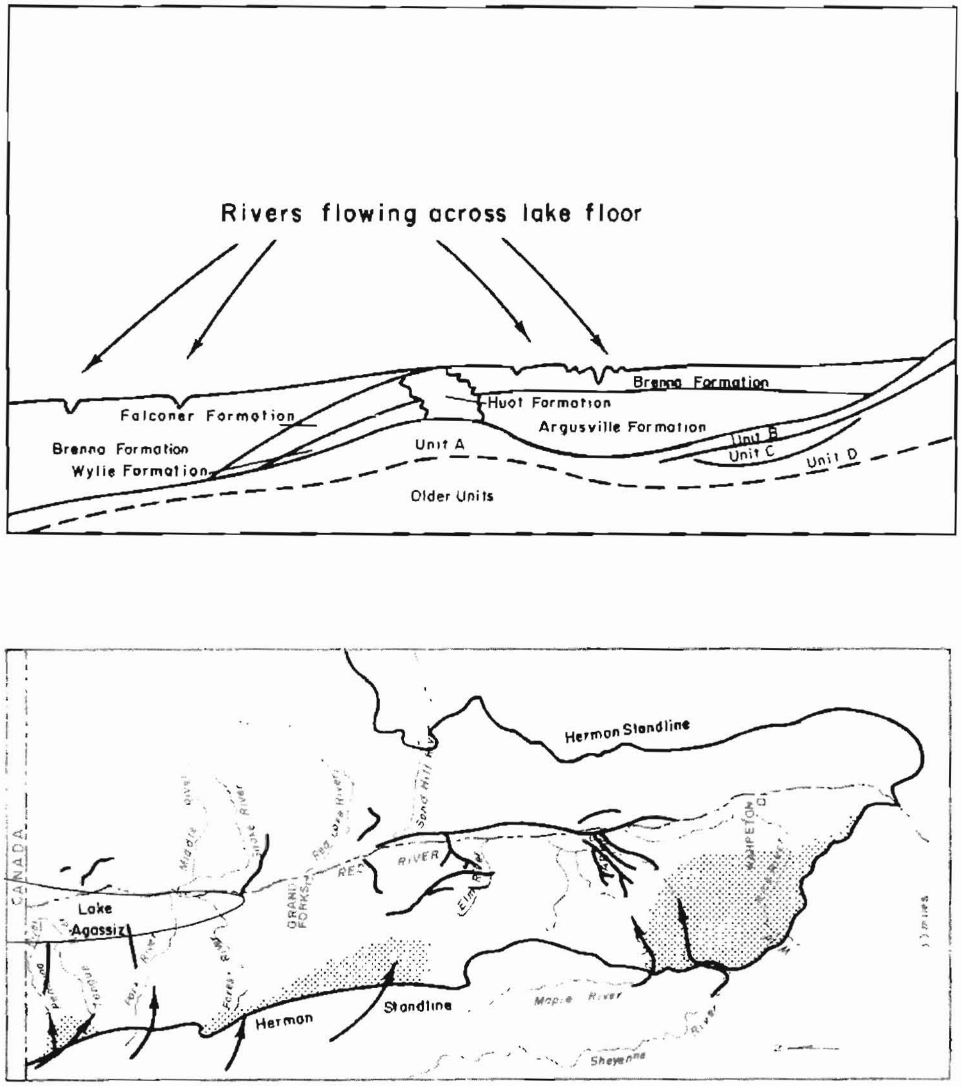

Figure 17. North-south cross section and map view of the Moorhead Phase in the Lake Agassiz basin.

risen back to the Campbell level; (3) When this eastern outlet reopened, Lake Agassiz again dropped, and by 10,500 B.P. was at the Ojata level; (4) A lower eastern outlet opened, and by 10,300 B.P., the level of Lake Agassiz had dropped below the Ojata level; (5) This lower eastern outlet became blocked by about 10,100 B.P., and Lake Agassiz rose back to the Ojata level. This level was maintained for about 200 years when the higher eastern outlet again was blocked by ice.

When the lake stood at the Ojata level in the Red River Valley during the Moorhead Phase, a delta, the Moorhead Delta, was formed where the Sheyenne and Maple Rivers emptied into Lake Agassiz at Fargo (figs. 18 and 19). As the lake continued to drop, these rivers extended their courses across the exposed lake floor. Smaller deltas, formed where other streams entered the lake, were probably common. There is evidence of three such deltas where streams entered the lake when it was below the Ojata level. One such delta is in northeastern Traill County (fig. 20), one is in central Walsh County (fig. 21), and the other one is in Pembina County (fig. 22).

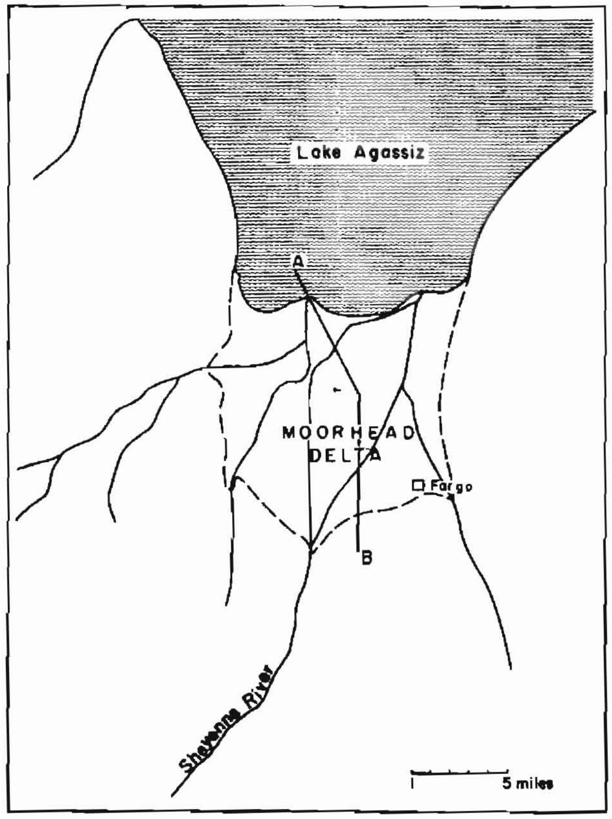

Figure 18. Map view of the Moorhead Delta.

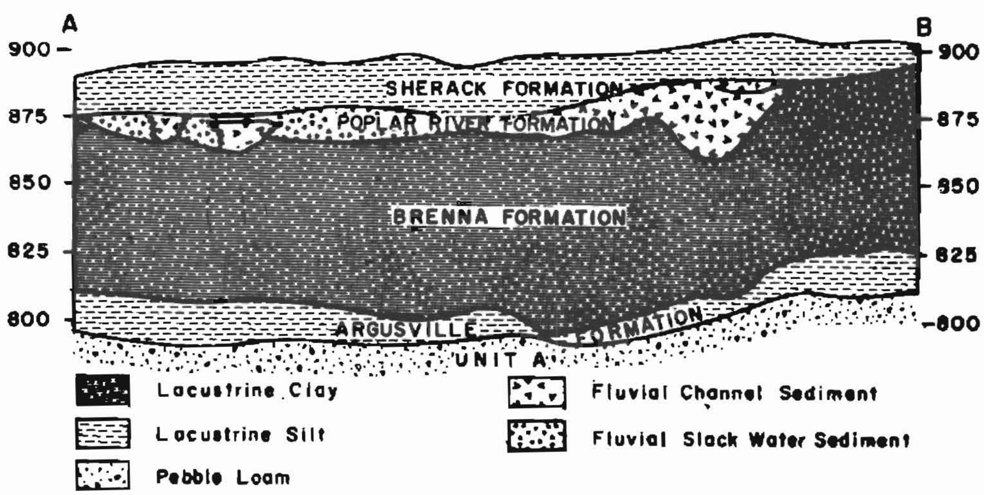

Figure 19. Cross section A-B (fig. 18) of the Moorhead Delta.

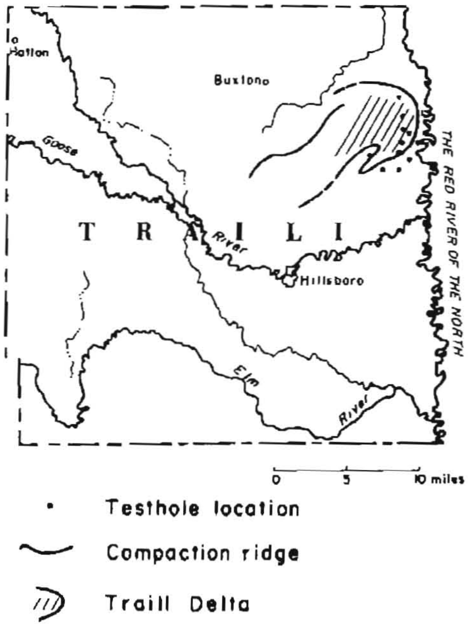

Figure 20. Map view of the Traill Delta.

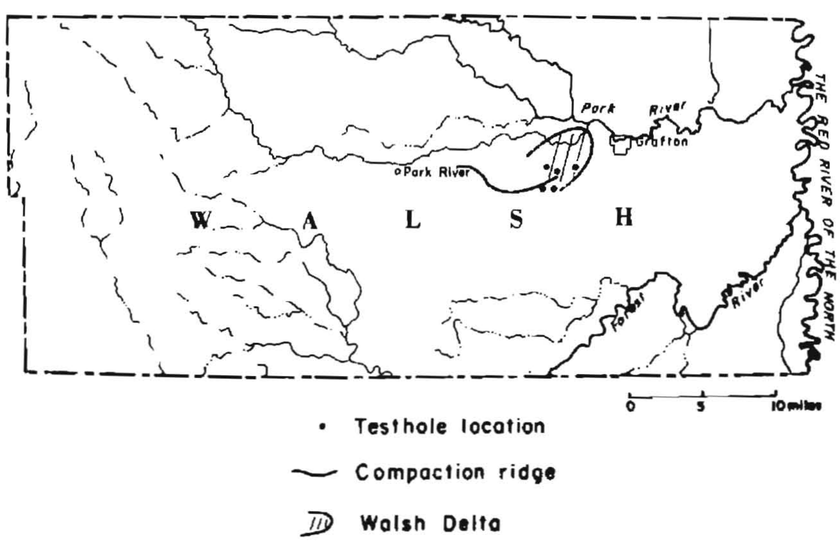

Figure 21. Map view of the Walsh Delta.

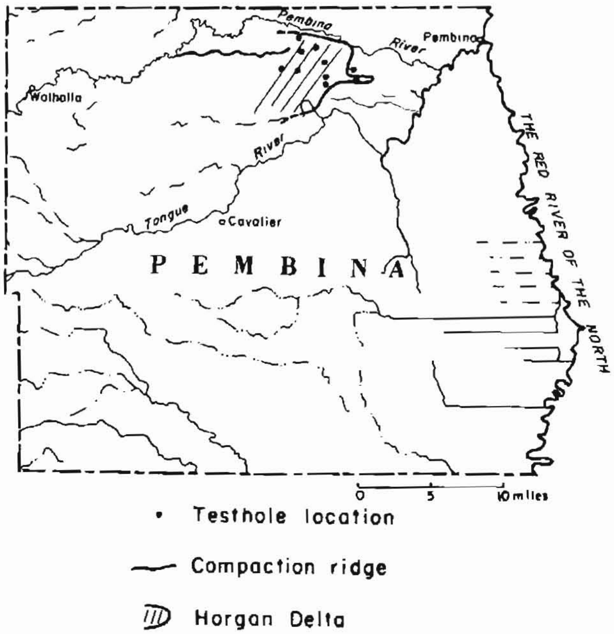

Figure 22. Map view of the Horgan Delta.

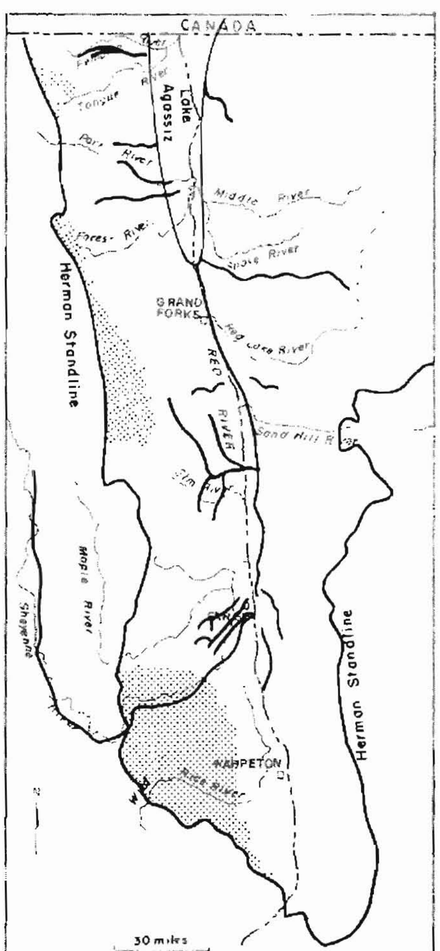

Figure 23. Drainage network across the Lake Agassiz basin during the low-water Moorhead Phase.

The drop of the lake exposed much of the lake floor to subaerial erosion. A drainage network similar to the present Red River system developed (fig. 23). Some areas between stream channels were high and dry, and others were low and marshy and characterized by deposition of highly organic silt and clay. When the lake rose back to the Ojata level, renewed growth of the Moorhead Delta took place.

The Poplar River Formation is the result of deposition during the Moorhead Phase. Deposition of the fluvial sediment of the West Fargo Member began with the drop of the lake to the Ojata level. The lower part of the Sherack Formation may have been deposited during the rise back to the Campbell level at about 10,700 B.P. The reopening of the eastern outlets led to renewed deposition of the Poplar River Formation across the exposed lake floor. During this time, when the lake floor was exposed, fluvial overbank sediment of the Harwood Member was deposited. The rise back to the Ojata level at about 10,100 B.P. brought about growth of the Moorhead Delta. In the center part of the basin, deposition of the Sherack Formation may have begun.

Lake Agassiz stood at the Ojata level for about 200 years (10,100 B.P. to 9,900 B.P.) when the higher eastern outlet again

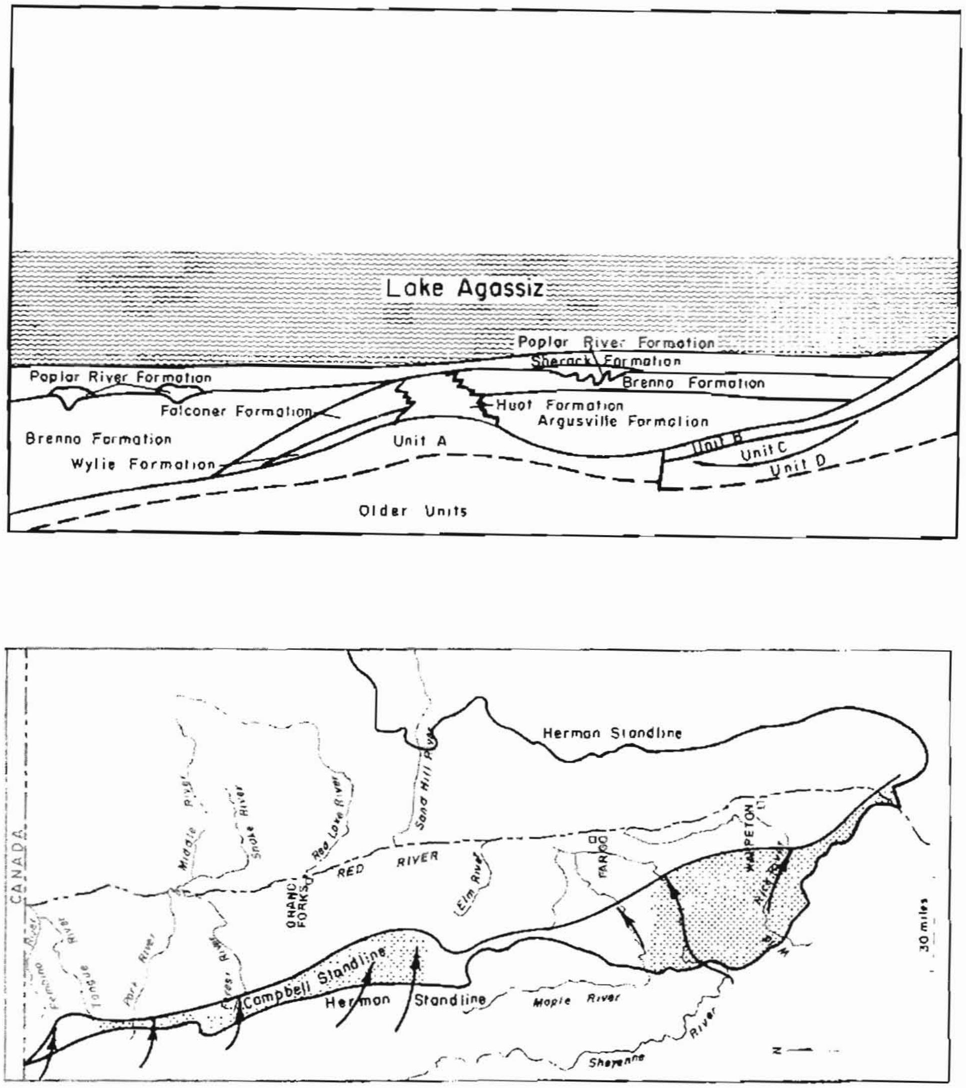

Figure 24. North-south cross section and map view of the Emerson Phase in the Lake Agassiz basin.

became blocked by ice, and the lake rose to the Campbell level. This marks the end of the Moorhead Phase.

Emerson Phase

The rise of Lake Agassiz back to the Campbell level at 9,900 B.P. marks the beginning of the high-water Emerson Phase (fig. 24). The ice had probably melted off the highlands to the west by this time, and the sediment source was no longer the Pierre shale but rather the glacial sediment on the uplands. The Sheyenne River brought glacially derived sediment into the lake. The Pembina River was no longer restricted to southward flow by ice on the east, and flowed directly eastward into the lake, building up the delta that had begun to form during the Lockhart Phase. These two rivers probably supplied the major part of the sediment to Lake Agassiz, at least on the western side of the lake. Rivers such as the Park, Turtle, Goose, and Elm also supplied sediment to the lake but in much smaller amounts. The lake stood at the Campbell level until about 9,000 B.P., when the eastern outlets were reopened (Elson, 1967), and Lake Agassiz drained from North Dakota for the last time.

The Sherack Formation was mostly deposited during the Emerson Phase.

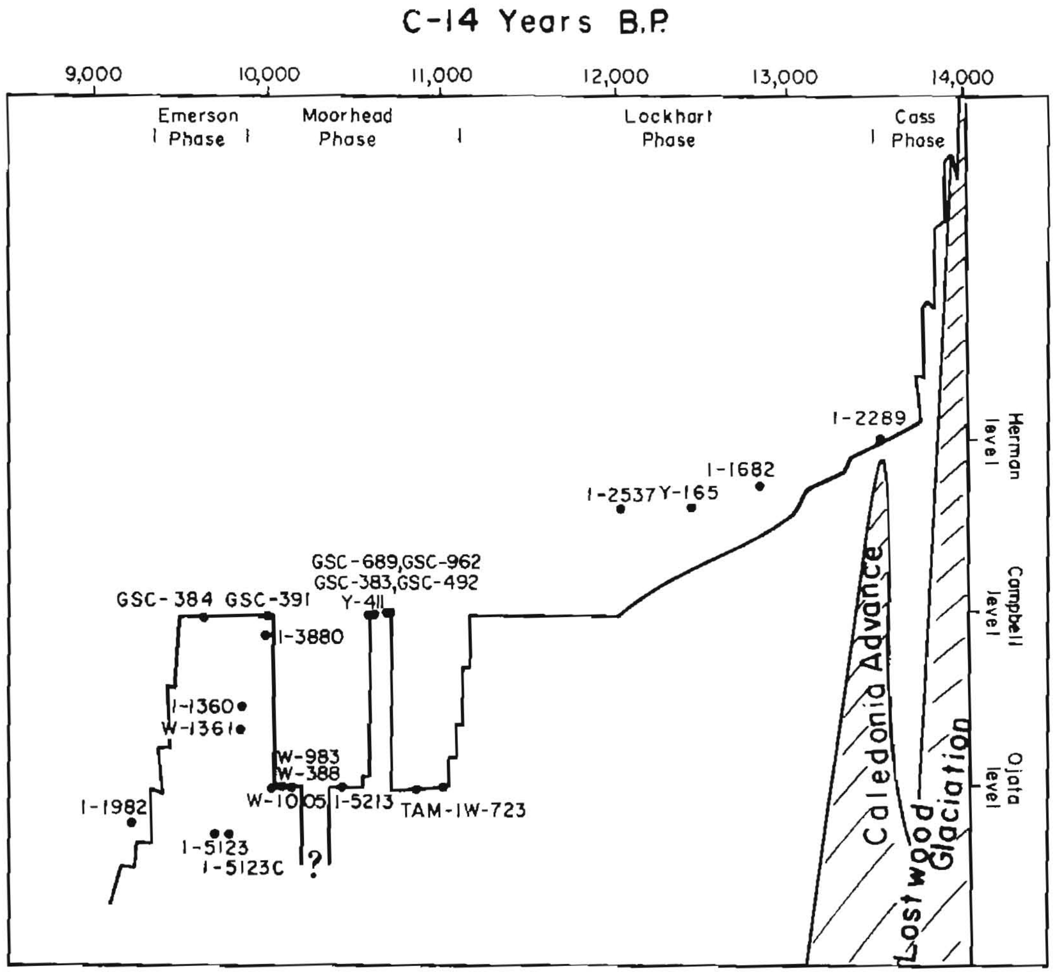

Figure 25. Diagram showing the relation between levels of Lake Agassiz and the radiocarbon chronology.

CHRONOSTRATIGRAPHY

Late Wisconsinan

The Red River Valley was entirely covered by ice of the Des Moines lobe, which did not reach its southern terminus in Iowa until about 14,000 B.P. (Wright and Ruhe, 1965). A date on clam shells (I-2289, 13,500±220, table 1) in a fluvial terrace just below the top of the Sheyenne Delta indicates this delta, or at least the upper part of it, had been formed by 13,500 B.P. The Cass Phase, then, had to have begun before that time (fig. 25).

The Caledonia Advance, that deposited the Falconer and Huot Formations, is correlated with the advance that produced the Edinburg Moraine in North Dakota and Darlingford Moraine in Manitoba (Clayton, 1966; Harris and others, 1974). Richie and Lichti-Federovich (1968) report a bog-bottom date of 12,800±350 B.P. (I-1687, table 1) that is behind the Darlingford Moraine and, therefore, post-dates this advance. So, the Cass Phase, which began before 13,500 B.P., ended before 12,800 B.P.

The time of the Lockhart Phase of Lake Agassiz is based on dates in alluvial material on the Assiniboine Delta (Y-165,

Table 1. *Carbon-14 dates associated with Lake Agassiz.*

Laboratory Number	Age (in Radiocarbon years B.P.)	Significance of Date
I-2289(1)	13,500±220	The sand overlying the clam shells is interpreted to be fluvial sediment incised below the top of the Sheyenne Delta. At least part of the Sheyenne Delta had been deposited prior to 13,500.
I-1682(2)	12,800±350	A bog bottom date behind the Darlingford Moraine in Manitoba that post-dates the Caledonia Advance.
Y-165(3)	12,400±420	Date on peat from an alluvial fill below the Herman level of Lake Agassiz established during the Lockhart Phase.
I-2537(1)	12,000±250	Date on clam shells in fluvial sediment that was deposited by the Sheyenne River flowing into Lake Agassiz. By this time the river had cut well below the top of the Sheyenne Delta.
W-723(1)	10,960±300	Date on wood in sediments associated with the Ojata beach.
TAM-1(1)	10,820±190	Independent laboratory check on W-723.
GSC-383(4)	10,600±150	Date on marl related in valley fill related to Campbell level.
GSC-492(4)	10,620±160	Date on clams in terrace above Assiniboine River and correlates with Campbell level of Lake Agassiz.
GSC-689(6)	10,920±150	Date on freshwater clams below terrace level corresponding to the Campbell level and records a rise back to the Campbell level during the Moorhead Phase.
GSC-902(5) GSC-870(5) GSC-797(5)	10,600±150 10,000±150 9,700±140	Plant detritus and wood 60, 25, and 15 feet below a terrace level in the lower part of the Assiniboine Delta. This terrace corresponds to the Campbell level and these remains were buried deltaic environment graded to the Campbell level.
Y-411(3)	10,550±200	Date on wood from same location as GSC-383.
I-5213(1)	10,340±170	Date on wood detritus in sediments associated with the Ojata Beach. As the lake level dropped below Ojata level during the Moorhead Phase.

(1)Moran and others, 1973.
(2)Richie and Lichti-Federovich, 1968.
(3)Elson, 1957.
(4)Lowdon and others, 1967.
(5)Klassen, 1969.
(6)Lowdon and Blake, 1970.

Table 1. *Carbon-14 dates associated with Lake Agassiz.*—Continued

Laboratory Number	Age (in Radiocarbon years B.P.)	Significance of Date
W-900[1]	10,080±780	Date is on wood in sediment associated with the Ojata Beach and is related to the Moorhead Phase.
W-1005[1]	10,050±300	Date is wood and wood trash in sediment associated with the Ojata Beach.
W-993[1]	9,900±400	Date is on wood from swamp deposits on the delta that was formed at Fargo during the Moorhead Phase.
W-388[3]	9,930±280	Date is on wood in the same geologic setting as W-993.
GSC-391[4]	9,990±160	Date on driftwood fragments in sediments associated with the Campbell level marking the end of the Moorhead Phase.
W-1360[1]	9,810±300	Date on wood that dates the rise of Lake Agassiz marking the boundary between the Moorhead Phase and Emerson Phase.
W-1361[1]	9,820±30	Date on wood in beach sediments above the Ojata level buried by the rising waters of Lake Agassiz at the end of the Moorhead Phase, marking the beginning of the Emerson Phase.
GSC-384[7]	9,580±220	Date on carbonaceous material in lagoon that was covered as the beach sediments of the Campbell strandline advanced across it during the Emerson Phase.
I-5123[1]	9,650±150	Date is wood from a tree that was probably killed by the rising waters of Lake Agassiz at the beginning of the Emerson Phase.
I-1982[1]	9,130±150	Date is on wood in lacustrine sediments deposited in an estuary cut into the Sheyenne Delta following the drop below Campbell level at the end of the Emerson Phase.
I-3880[8]	9,940±160	Date is on driftwood below the Campbell level that was buried by the rising waters of Lake Agassiz at the end of the Moorhead Phase.

(1)Moran and others, 1973.
(3)Elson, 1957.
(4)Lowdon and others, 1967.
(7)Lowdon and Blake, 1968.
(8)Ashworth and others, 1972.

12,400±420, table 1) and clam shells in fluvial sediment in the Sheyenne Delta (I-2537, 12,000±250, table 1).

The beginning of the Moorhead Phase at about 11,000 B.P. is based on dates from wood in sand (W-723, 10,960±300; TAM-1, 10,820±190) that mark the drop of Lake Agassiz to the Ojata level. The rise back to the Campbell level between 10,700 B.P. and 10,500 B.P. is based on dates of material collected by Elson (1967) and Klassen (1969) in Manitoba (GSC-383, 10,600±150; GSC-902, 10,600±150; GSC-492, 10,670±160; GSC-383, 10,600±150; Y-411, 10,550±200). A date of 10,340±170 (I-5213) on forest litter in sand indicates that the Lake Agassiz was back to the Ojata level by that time. Several C-14 dates at the Ojata level on wood in beach sediment give good agreement for the age of the Moorhead Phase (W-900, 10,080±780; W-1005, 10,050±300; W-993, 9,900±400; W-388, 9,930±280).

Holocene

The rise of Lake Agassiz back to the Campbell level marking the beginning of the Emerson Phase is dated at about 9,900 B.P. (GSC-391, 9,990±160; I-3880, 9,940±160). Two dates on wood under gravel in Traill County (W-1360, 9,810±300; W-1361, 8,820±300) confirm the beginning of the Emerson Phase. A date on driftwood of 9,650±150 B.P. (I-5123) about 2 feet above the base of the Sherack Formation indicates that deposition of this unit had already begun before this time. Brophy (1967) dated wood from an estuary cut into the Sheyenne Delta below the Campbell level at about 9,130±150 B.P. (I-1982). The Emerson Phase then had to close about this time.

DISCUSSION

Depositional Environments

Three depositional environments for the offshore sediment of Lake Agassiz can be described: (1) the environment that existed during deposition of Wylie and Argusville Formations, (2) the environment that existed during deposition of the Brenna Formation, and (3) the environment that existed during deposition of the Sherack Formation.

The deposition of the Argusville and Wylie Formations took place as the ice margin retreated down the Red River Valley. Probably most of the uplands to the west were still covered by ice, so most of the sediment in the basin was locally derived. Meltwater coming off the ice front was relatively clean and contributed some of the coarser sediment found in the Argusville and Wylie Formations. The Sheyenne River was flowing in a generally southward direction cutting through Pierre shale.

Deposition of the Brenna Formation occurred in the basin when the ice, for the most part, was out of the Red River Valley. During this time, the ice was, for the most part, off the uplands. The Sheyenne, Goose, Park, and Pembina Rivers and possibly the Maple and Elm Rivers generally flowed southward along the base of the Pembina Escarpment. While the ice was still in the Valley, drainage was forced southward along the escarpment. During the time of deposition of the Brenna Formation, these rivers maintained this southerly flow, forming or continuing to build the Sheyenne, Galesburg, Elk Valley, and Pembina Deltas. The major source of sediment was still the Cretaceous bedrock, mostly the shale of the Pierre Formation but also, to some extent, shale of the Niobrara and Carlile Formations.

Deposition of the Sherack Formation took place in Lake Agassiz when the previously southward flowing streams flowed generally eastward into the lake. The Pembina and Sheyenne Rivers were the major source of sediment supply. Growth of the Pembina Delta was primarily in an eastward direction. Although the Goose and Elm Rivers south of the Edinburg Moraine supplied sediment to the lake, this was probably minor compared to that supplied by the Sheyenne and Pembina Rivers.

The Sherack Formation contains more clay south of the Edinburg Moraine than north of it. North of the moraine the Pembina River supplied large amounts of relatively coarse glacially derived sediment to the center of the Agassiz basin. South of the Edinburg Moraine, the Sheyenne River flowed generally southeastward, adding sediment similar to that of the Pembina River to the southern part of the Agassiz basin. The Elm and Goose Rivers were probably the only sediment source for the area between the Edinburg Moraine and the Sheyenne River. Probably neither of these two rivers supplied significant sediment to that part of the basin. The sediment that was deposited here (between the Edinburg Moraine and Sheyenne River) was the furthest away from any sediment source.

In summary, the textural variations of the offshore lacustrine sediment in the Agassiz basin are the result of (1) sediment source (whether it was the bedrock shale or glacial sediments), and (2) nearness of the ice margin.

Engineering Application

General

The stratigraphic units defined in this report can also be defined on the basis of their engineering properties. These properties include water content, unit weight, liquid limit, plasticity index, unconfined-compressive strength, consistence index, and standard-penetration test.

Soil as used in this report is meant in the engineering sense. That is, it is any earthen material (sediment), excluding bedrock, composed of loosely bound mineral grains of various sizes and shapes, organic material, water, and gases (The Asphalt Institute, 1969, p. 5).

Water content (Hough, 1969, p. 40) may be defined by the following equation:

$W\% = \frac{W_w}{W_s} \times 100$ in which $W\%$=water content, dry weight basis, W_w=weight of water in a given soil mass, and W_s=weight of solids in the soil mass.

Unit weight (dry unit weight) (Hough, 1969) is defined as the weight of soil solids per unit volume and is expressed as $\gamma_D = \frac{W_s}{V_t}$ in which γ_D=dry unit weight of soil, W_s=weight of solids in a given soil mass, and V_t=total volume of the soil mass.

Liquid limit (LL) is defined as the lowest water content corresponding to the arbitrary boundary between the liquid and plastic states of a soil. This is the water content at which a pat of soil, cut by a groove of standard dimensions, will flow together for a distance of ½ inch under the impact of 25 blows in a standard liquid limit apparatus (The Asphalt Institute, 1969).

Plastic limit (PL) is the water content corresponding to an arbitrary boundary between the plastic and semisolid states of a soil. This is the water content at which a soil will just begin to crumble when rolled into a thread approximately 1/8 inch in diameter (The Asphalt Institute, 1969).

Plasticity index (PI) is the numerical difference between the liquid and plastic limit. It is the range of water content over which a material is in the plastic state (Hough, 1969, p. 48).

The Atterberg limits (liquid limit and plastic limit) and plasticity index have their most common application in highway construction. Generally a soil with a high liquid limit, is clay with poor engineering properties. A low plasticity index indicates a granular soil with little or no cohesion and plasticity (The Asphalt Institute, 1969).

Unconfined-compressive strength is determined by axially loading a cylindrical clay specimen without lateral support. The compressive stress at failure on a cross section of the specimen is termed the unconfined-compressive strength (q_u) (Hough, 1969, p. 232).

Consistency index is a value defined by the North Dakota State Highway Department by the following equation:

$C_I = \frac{LL - W\%}{PI}$, in which C_I=consistency index, LL=liquid limit of a given soil sample, W%=water content of the soil sample, and PI=plasticity index of the soil sample.

The consistency index is a measure of the compressibility of a soil under load. The higher the numerical value the less likely is compression under load to be significant. Soils with consistency indices greater than 100 can be considered to be suitable foundation material for footings and poles.

The *standard-penetration test (SPT)* is the number of blows a 140-pound hammer dropped 30 inches onto a split-barrel sampler to drive that sampler 1 foot. This test is one of the most practical methods of determining the density or consistency of the material in place (Hough, 1969, p. 553).

The following is a discussion of the engineering characteristics of the different units in the Agassiz basin described in this report. Table 2 is a summary of the engineering properties for all units described here. Plate 3 is a summary of some of the properties listed in table 2 for the *continuous* units in the Lake Agassiz basin.

Unit 10

As mentioned previously, many of the engineering properties used in this report are a function of clay content. The clay content of unit 10 varies considerably in the Agassiz basin largely because it contains sediment of different origins. For the most part, however, water content appears to be the least affected by clay content variability (pl. 3). The variability of unit 10 is shown most by liquid limit, plasticity index, unconfined-compressive strength, and consistency index (pl. 3; appendix A).

Unit 10 need not be considered in engineering problems because it is generally less than 6 feet thick. For nearly all types of construction it would probably be excavated before any construction takes place. In those areas where it is quite thick (alluvial fills along the major rivers may be more than 50 feet thick), unit 10 is mostly clay, and values for water content, liquid limit, and plasticity index are on the higher range listed in table 2. Unit weight, unconfined-compressive strength, and consistency index tend toward the lower values listed.

Sherack Formation

The Sherack Formation has the best engineering properties of the lacustrine deposits in the Agassiz basin for highway construction and building foundations. The Sherack Formation south of the Edinburg Moraine to north of Hankinson, in Richland County, contains more clay than this same formation north of the moraine. This increased clay content is reflected in a somewhat higher liquid limit, plasticity index, and water content (pl. 3). The unit dry weight of this formation between the two areas is not very much different. However, in the southern, more clay-rich part of the Sherack Formation the fluctuation of dry weight from one site to another is much less and reflects a greater uniformity in the sediment size.

Just north of the Edinburg Moraine, where the Sherack Formation directly overlies the Falconer Formation, and south of about Hankinson this unit shows a marked decrease in clay content. In both these areas the liquid limit drops below 40 percent and plasticity index drops below 20 percent (appendix A). Unit dry weight and standard-penetration tests are higher in these two areas than for the rest of the formation. In these areas, the Sherack Formation may provide a suitable foundation for highway construction and light structures without major engineering modifications.

Poplar River Formation: West Fargo Member

The engineering properties given for this unit in table 2 are applicable only to those parts of the member that contain clay. The various engineering properties used in this report, with the exception of the standard-penetration test, are applicable only for soils that contain clay and silt because these engineering tests cannot be performed on sand or gravel, which make up much of the West Fargo Member. The values given for the West Fargo Member were obtained from that part of the member that contained enough fine-grained sediment to use these tests; the values given for the unit are in all cases minimum values.

The buried channel deposits of the West Fargo Member are saturated and under confined hydrostatic conditions; in some places the head is above ground surface. A foundation built on this member or a footing placed in it is subject to quick

Table 2. *Range of Site Means of Engineering Properties of Lithostratigraphic and Other Units in the Lake Agassiz Basin.*

Unit	W(%)	(pcf)	LL(%)	PI(%)	q_u(psf)	C_I	SPT
Unit 10	10-56	75- 96	27- 93	6-65	212-3474	20-103	7-42
Sherack Formation	17-56	70- 98	27- 92	3-60	794-3065	22- 86	7-34
West Fargo Mbr.- Poplar River Fm.	22-40	80- 95	22- 39	5-17	1222-3980	62-120	21-40
Harwood Mbr.- Poplar River Fm.	39-67	61- 81	49- 96	15-57	891-2547	33- 90	8-21
Brenna Fm.- North of Edinburg Moraine	62-88	50- 67	63-104	20-68	806-1733	16- 54	4- 7
Brenna Fm.- South of Edinburg Moraine	42-69	58- 79	48- 93	24-57	882-2622	34- 65	4-14
Falconer Formation	16-49	73-115	27- 71	12-40	937-5726	40- 87	7-22
Huot Formation	37-63	63- 86	62- 66	31-35	855-1638	14- 98	3- 8
Wylie Formation	38-60	56- 82	39- 87	22-53	831-2841	15- 75	7-15
Argusville Formation	38-63	62- 85	42- 85	16-50	1347-2993	11- 58	4-16
Unit A	10-24	81-117	18- 37	4-17	1237-5801	80-179	
Unit B	20-29	94-109	28- 40	10-20	828-4343	46- 80	
Unit C	23-50	71-100	45- 63	23-35	1581-4295	26-101	8-27
Unit D	8-19	113-123	18- 34	3-17	1955-6169	54-166	

Data summarized from values listed in Appendix A.

conditions with a resultant sinking of the foundation or footing.

A grain elevator built over such a setting in Fargo collapsed in 1952 as a result of the high pore-water pressure in this member. The elevator was built on a slab foundation in the Sherack Formation, and a combination of uneven loading and elevated pore-water pressure caused its collapse (Nordland and Deere, 1970). Bell (1968) described construction of a railroad underpass across the West Fargo Member in Fargo. Pilings were driven to refusal in what seemed a suitable foundation. However, as water was released from this unit the pilings sank. Sewer line and other excavations encountering the West Fargo Member are subject to collapse because of piping and running sand.

Poplar River Formation: Harwood Member

The Harwood Member is only of minor significance as an engineering unit. It is present in only a few places and generally associated with the West Fargo Member. Because it is fluvial overbank sediment it should behave about the same as unit 10. Its engineering properties are in the same range as that of unit 10 (table 2).

Brenna Formation North of the Edinburg Moraine

The Brenna Formation provides the weakest foundation of all the units described in this report (table 2). It has a generally low unit weight, consistency, and unconfined-compressive strength (pl. 3). The extreme low values of standard-penetration resistance point out the undesirability of this soil as a foundation material. Excavations or embankments that cut into the Brenna rarely stay open long and slumping is a very serious hazard. In the center part of the basin the Sherack Formation overlying the Brenna is at least 20 to 30 feet thick. Towards the margin of the basin, the Brenna can be within 10 to 15 feet of the surface. Because the Brenna Formation is such a weak unit it is necessary to determine its depth before undertaking construction of most types of structures.

In Grand Forks County, part of a county road 5 miles east of Johnstown has had to be rebuilt several times. Here the Brenna Formation is near the surface and a drainage ditch was cut into it. Slumping of the ditch and road embankment has been a recurring problem. Repair of the road was accomplished by removing the toe of the slump and building up the road. This provided another driving force to cause further slumping. The road had to be relocated so it is not along the drainage ditch where the slumping has occurred. Grain elevators in the Red River Valley are commonly built on slab foundations that rest on or near the Brenna Formation. Uneven loading of grain in such a structure can provide the driving force to cause failure of the foundation and is similar to stepping off a dock into a boat that is not tied down. The failure of a grain elevator near Transcona, Manitoba, was caused by uneven distribution of grain inside the structure (Mindess, 1972). Although I have never personally seen it, it is my understanding that the foundation of the North Dakota State Mill Elevator at Grand Forks is subject to movement as grain is shifted about, particularly in the spring.

Argusville Formation and the Brenna Formation South of the Edinburg Moraine

The Argusville Formation and the Brenna Formation south of the Edinburg Moraine have only slightly different lithology and about the same engineering characteristics (pl. 3). As a practical matter they can probably be treated as one engineering unit. For the most part these two units can be considered as a somewhat transitional engineering unit between the Sherack Formation and the Brenna Formation north of the Edinburg Moraine. They are not as strong as the Sherack nor as weak as the northern Brenna. For the most part, the same caution used in construction over the northern Brenna Formation should be observed in the areas where the southern Brenna and Argusville Formations are present.

Falconer Formation

The Falconer Formation is made up mostly of glacially derived pebble-loam and should be expected to have relatively desirable engineering characteristics. It does, however, contain 20 to 50 percent clay, which gives it a low consistency index (pl. 3). Towards the south, near the Huot Formation, the Falconer generally increases in clay content, with a resultant decrease in consistency index and strength. The large variation in unconfined-compressive strength is probably a result of the variable clay content. The standard-penetration resistance of the Falconer in most places is not much more than that of the Brenna Formation and it is not much stronger.

Huot Formation

The Huot Formation varies considerably in engineering properties, but it is generally a weak material. Along the Red Lake River, where this formation is at the surface, it slumps easily. Its engineering properties are similar to that of the Sherack-southern Brenna-Argusville, and it is expected to behave in a similar manner.

Wylie Formation

The Wylie Formation is lake sediment that is stratigraphically equivalent to the Argusville Formation. It has somewhat different engineering characteristics than the Argusville Formation because it has incorporated within it pebble-loam of the Falconer Formation as a result of overriding by the Caledonia Advance. For the most part, the Wylie Formation is difficult to characterize as an engineering unit because of its relative thinness and because of incorporation of the Falconer. Depending on where it is sampled, both laterally and vertically, it could either be very similar to the Sherack, southern Brenna and Argusville Formations, or to the Falconer Formation. In either case, any foundation that required pilings that deep should be driven into the underlying unit A.

Units A, B, C, D

Units A, B, and D appear to provide suitable foundation for nearly all types of construction. Unit C, because it is composed primarily of clay and material incorporated from unit D, is expected to have engineering characteristics similar to the Wylie Formation. Any foundation that required pilings deep enough to encounter unit C should be driven into unit D, so further consideration of unit C is unnecessary.

Structures along Interstate Highway 29 that rest on pile foundations are all supported by either units A, B, or D. The high-rise buildings in the Fargo area that rest on pile foundations are set on unit A.

Water content of units A and D are low, generally less than 20 percent (pl. 3). Unit B has a range of water content slightly above 20 percent, which is probably a reflection of a somewhat higher clay content than either unit A or D. Data on dry unit weight is limited for unit A, and unit D has a consistently higher dry unit weight than unit B. The consistency index of unit B is less than 80 (pl. 3) and suggests that this unit is more subject to compression under load than either unit A or D.

Table 2 does not give values for standard-penetration for units A, B, and D because these data are meaningless when blow counts are greater than 100 per foot. In only a few borings were penetrations given in blow counts per foot. In most places, 100 hammer blows caused a penetration of less than ½ foot. As standard-penetration tests are not necessarily a linear relationship, these counts were not converted to a per-foot basis.

Summary

The study of the offshore sediment of Lake Agassiz in the Red River Valley serves two functions: (1) It provides a stratigraphic framework for the sediment in the basin, which can be used to describe the geologic history of Lake Agassiz. (2) This same stratigraphic framework can be used in describing the engineering properties of the sediment in the Lake Agassiz basin.

Summary of Geologic History

(1) Lostwood Glaciation (about 14,000 B.P.).—The entire Red River Valley was covered by ice. The drainage divide at Browns Valley, Minnesota, was exposed by

retreat of the ice margin at least as far north as northern Richland County. Meltwater ponded behind this divide. Subsequent readvance of the ice overrode the deposited lake sediments.

(2) Cass Phase (before 13,500 B.P. to before 12,800 B.P.).–The ice margin had again retreated far enough to expose the southern drainage divide at Browns Valley, Minnesota. Another lake was formed as meltwater ponded behind this divide. Strandlines above Herman level formed. This was the time of deposition of the Wylie and the lower part of the Argusville Formations.

(3) Caledonia Advance (before 12,800 B.P.).–The generally retreating Late Wisconsinan ice readvanced as far south as Traill County. The extent of this advance is marked by the clay-rich pebble-loam of the Huot Formation. The Falconer Formation was deposited as a result of this advance. Deposition of the Argusville Formation continued in the southern part of the basin.

(4) Lockhart Phase (before 12,800 B.P. to 11,000 B.P.).–The second high-water phase of Lake Agassiz began in the southern end of the basin, and the lake spread northward as the ice margin retreated. This was the time of deposition of the Brenna Formation.

(5) Moorhead Phase (11,000 B.P. to 9,900 B.P.).–The opening of eastern outlets into the Lake Superior basin resulted in the draining of Lake Agassiz. There were several lake fluctuations, but most of the time the lake floor was subjected to subaerial weathering. Streams flowed across the newly exposed lake floor, depositing the Poplar River Formation.

(6) Emerson Phase (9,900 B.P. to 9,000 B.P.).–The eastern outlets were blocked by ice, and Lake Agassiz rose to the Campbell level. Deposition of the Sherack Formation took place during the Emerson Phase.

(7) Post-Emerson Phase (after 9,000 B.P.).–The eastern outlets reopened, and Lake Agassiz drained from North Dakota for the last time.

Summary of Engineering Properties

(1) Unit 10 is the surface unit over nearly all of the center of the basin. It contains alluvial and fluvial sediment and fill materials. In those areas where it is thick, it is mostly alluvium. It has a wide range of water content, unit weight, liquid limit, plasticity index, unconfined-compressive strength, consistency index, and standard-penetration resistance. It has generally high water content and Atterberg limits and generally low strength.

(2) The Sherack Formation has the best engineering characteristics of the offshore sediment in Lake Agassiz. It tends to have lower water content and Atterberg limits and higher unit weight, consistency index, unconfined-compressive strength, and standard-penetration resistance than the other offshore units.

(3) The West Fargo Member of the Poplar River Formation is under confined piezometric conditions, and, in places, the piezometric head is above the land surface. Excavations or foundations in it are subject to quick conditions unless steps are taken to alleviate the high pore pressures.

(4) The Harwood Member of the Poplar River Formation is similar to the Sherack and Falconer Formations and Unit 10. As an engineering unit it is rather insignificant because of its thinness and sporadic distribution.

(5) The Brenna Formation in the northern part of the basin is a very weak unit. It has high water content and Atterberg limits and low unit weight, consistency index, unconfined-compressive strength, and standard-penetration resistance. Excavations into this unit or heavy loads on it are subject to failure. The southern part of the Brenna Formation has engineering properties intermediate to those of the Sherack Formation and the northern part of the Brenna Formation.

(6) The Falconer Formation, although it is primarily pebble-loam, has rather poor engineering characteristics because of its high clay content.

(7) The Huot Formation varies considerably in engineering properties, but it is generally a weak material. In most places it would be expected to behave similar to the Sherack Formation and the southern part of the Brenna Formation.

(8) The Wylie Formation is expected

to have similar engineering characteristics to the Argusville Formation. It has incorporated within it material from the Falconer Formation, so it is difficult to characterize it as an engineering unit. The relative thinness and limited distribution reduce its importance as an engineering unit.

(9) The Argusville Formation has engineering properties similar to those of the southern part of the Brenna Formation.

(10) The pebble-loam units underlying Lake Agassiz sediment have generally low water content and Atterberg limits and high unit weight, unconfined-compressive strength, consistency index, and standard-penetration resistance. These units provide a suitable foundation for nearly all types of construction.

APPENDIX A

The engineering data summarized here was obtained from data supplied by the North Dakota State Highway Department. At least two borings were drilled at each site listed. Nearly all borings were drilled deep enough to encounter either Unit A or D (pls. 1 and 2).

Engineering data collected for each sampled interval was placed into a stratigraphic unit based on the descriptive log of each boring. In some of the borings, some stratigraphic units were not recognized except in the engineering data. For example, the Wylie Formation was often not recognized by the geologist or engineer writing the lithologic descriptions and was included with the Falconer Formation; however, the engineering data commonly indicates its presence by a zone of higher water content, liquid limit, plasticity index, and consistency index.

The data for each stratigraphic unit encountered at each site was punched on computer cards and processed through the University of North Dakota Computer. A mean and standard deviation for each site unit was obtained.

The contact between any two units at a site was commonly at different elevations in each separate boring. To get an average elevation for these unit contacts the following method was used: (1) An average surface elevation was determined by adding the surface elevations of each boring and dividing by the number of borings. (2) An elevation of each sampled interval was determined by subtracting the mean depth of that interval and subtracting from the average surface elevation. (3) All the engineering data associated with that mean depth and calculated elevation was sorted on the basis of elevation for each unit. (4) For most sites this resulted in situations where the highest elevation for the underlying unit was higher than the lowest elevation for the overlying unit. The contact between the two units was placed at the top of the highest elevation for the underlying units. At some sites, this method showed that some sampled intervals were originally assigned to the wrong unit because the engineering data indicated that these would be better placed in either the overlying or underlying unit, and the contacts were adjusted accordingly.

The following notations are used in the column headings for the basic data:

Site No. –The first number indicates the North Dakota highway number and the second number indicates the structure number.

Sd –Sand content (0.074 millimetres to 2.0 millimetres), in percent by weight of total gravel-sand-silt-clay content.

St –Silt content (0.005 millimetres to 0.074 millimetres), in percent by weight of total gravel-sand-silt-clay content.

Cl –Clay content (less than 0.005 millimetres), in percent by weight of total gravel-sand-silt-clay content.

W% –Water content.

γ_D –Dry unit weight, in pounds per cubic foot.

LL –Liquid limit, in percent.

PI –Plasticity index, in percent.

q_u –Unconfined-compressive strength, in pounds per square foot.

C_I –Consistency index.

SPT –Standard-penetration test, in blows per foot.

Appendix A—Continued

Site No.	Location Twp.-Range-Section	Unit	Elevation of Top (in feet)	Sd-St-Cl	W%	γ_D	LL	PI	q_u	C_I	SPT
66-12	159-51-25NE¼	Unit 10	800	14-24-62	36	71	58	26	2990	97	14
		Brenna	780	7-14-79	62	67	65	27	1016	51	4
		Unit A	638								
SP-3514*	161-50-7NW¼NW¼NW¼	Unit 10	793								
		Sherack	791								14
		Brenna	782								4
		Brenna Transition	688								12
		Unit A	654								
29-16	158-51-34NE¼NE¼NE¼	Unit 10	806	2-48-50	25						16
		Sherack	796	1-46-53	45	74	51	26	1157	43	10
		Brenna	769	0-12-88	62	64	88	52	1583	51	7
		Brenna Transition	672	6-23-70	48	74	65	39	2230	73	12
		Unit A	651	10-76-13	16	109	24	6	2362		
29-17	158-51-34SE¼SE¼NE¼	Unit 10	784	0-54-45	56						7
		Sherack	777		43	77	59	32	1447	54	8
		Brenna	761	0-22-78	63	64	87	53	1691	48	5
		Falconer	676	26-40-25	45						7
		Unit A	661	39-45-11	15	117	24	8	2248	132	
29-18	157-51-3SW¼SW¼SW¼	Unit 10	804	2-53-45	24						23
		Sherack	800	1-43-56	40	79	54	208	2455	66	14
		Brenna	775	0-14-86	63	63	87	54	1413	41	6
		Falconer	674	24-39-29	46	74	67	38	2008	53	12
		Unit A	672	39-40-12	12	114	23	9		142	
29-19	157-51-15SE¼SE¼SE¼	Unit 10	805		26						36
		Sherack	803	4-43-55	38	85	54	31	2367	61	14
		Brenna	778	0-15-85	68	62	90	54	1235	38	5
		Brenna Transition	685	1-29-70							
		Falconer	681	29-37-29	38	74	71	40	2267	63	10
		Wylie	678	8-37-55							
		Unit A	669	40-36-14	14	107	32	16	2638	88	
29-20	157-51-26SW¼SW¼SW¼	Unit 10	804	3-48-49	27		56	33			24
		Sherack	797	1-53-46	40	82	46	21	1627	42	11
		Brenna	778	1-22-77	67	61	90	56	1248	43	5
		Falconer	694	23-39-29	21	105	36	18	2687	59	18
		Wylie	684	1-26-72							
		Unit A	678	40-38- 9	11		26	11			
29-21	156-51-4SE¼SE¼SE¼	Unit 10	803	2-45-53	31		60	36			21
		Sherack	794	2-44-55	44	77	52	30	1636	42	7
		Brenna	774	0-13-87	67	60	98	63	1464	43	4
		Brenna Transition	700	1-28-72	54	67	78	43	1854	50	6
		Falconer	695	24-38-30	16	115	27	12		70	
		Unit A	687	44-33-16	12		19	5			
29-22	156-51-16SE¼SE¼SE¼	Unit 10	802	2-39-51	30		62	36			26
		Sherack	792	2-41-58	40	79	63	36	2450	54	10
		Brenna	775	1-14-86	66	60	94	60	1462	46	5
		Brenna Transition	693								
		Falconer	692	22-41-30	18	110	32	15	5726	87	20
		Unit A	681	42-38-10	12		19	6		132	

*N.D. State Highway Department Special Project 3514.

Appendix A—Continued

Site No.	Location Twp.-Range-Section	Unit	Elevation of Top (in feet)	Sd-St-Cl	W%	γ_D	LL	PI	q_u	C_I	SPT
29-23	156-51-27NW¼NW¼NW¼	Unit 10	794	2-35-63	38	94	93	65	2887	93	24
		Sherack	784	1-42-57	48	76	61	35	2012	59	9
		Brenna	764	1-11-88	64	62	98	65	1260	47	7
		Brenna Transition	698	0-27-73	54	69	81	47	2254	56	10
		Falconer	694	26-37-27	17	115	30	14	2390	82	22
		Unit A	677	24-50-18	14	88	22	9	2754	122	
29-24	156-51-27SW¼SW¼SW¼	Unit 10	803	2-46-53	29		60	37			25
		Sherack	796	3-48-51	43	79	54	28	2002	42	6
		Brenna	778	0-17-83	69	59	97	62	1733	48	
		Brenna Transition	708	0-29-71	53						9
		Falconer	704	27-42-23	18	112	27	12	2448	74	14
		Unit A	684	29-48-14	13		22	7		117	
29-25	156-51-9NE¼NE¼NE¼	Unit 10	804		28						12
		Sherack	801	8-46-50	40	80	58	34	2322	53	11
		Brenna	778	0-17-83	71	58	99	65	1114	42	6
		Brenna Transition	709								
		Falconer	705	26-40-25	21	94	29	14	2294	64	13
		Unit A	677	29-42-17	15		28	10		134	
29-26	156-51-16SE¼SE¼SE¼	Unit 10	809	1-44-55	28		68	40			34
		Sherack	801	1-51-48	38	82	57	31	2021	55	15
		Brenna	777	1-21-79	70	58	92	56	1298	43	6
		Brenna Transition	714	1-28-71	60	64	77	39	777		6
		Falconer	700	28-40-26	20	113	16			75	15
		Wylie	680	17-36-48	39	82	50	27		40	14
		Unit A	670	36-38-14	13		23	7		125	
29-28	155-51-34SW¼NW¼SW¼	Unit 10	808	2-39-58	37	86	53	31	2378	74	11
		Sherack	800	0-56-44	46	75	46	22	1964	24	7
		Brenna	771	1-14-86	73	58	98	63	1388	39	6
		Falconer	708	28-41-27	19	112	28	14	1477	73	19
		Unit A	685	44-25- 8	12		18	5			
29-31	154-51-27NW¼NW¼NW¼	Unit 10	815	1-65-34	30						8
		Sherack	811	2-42-57	46	77	53	29	1711	38	8
		Brenna	776	0-10-90	74	57	104	68	1188	43	6
		Falconer	715	19-40-35	27	96	38	21	1655	55	14
		Wylie	686	0- 8-92	57	56	87	53	1094	24	15
		Unit A	673	16-68-12	16		22	4			
29-33	153-51-3SE¼SE¼NW¼	Unit 10	808	1-54-45	34						
		Sherack	801	5-50-44	45	80	47	22	1655	40	6
		Brenna	782	0-12-88	85	52	98	58	924	16	4
		Brenna Transition	730	3-33-64	52	74	50	25	933	33	5
		Falconer	720	8-64-26	26	97	37	13	1283	54	12
		Unit A	690	50-36- 6	18						
29-34	153-51-11SE¼SE¼SW¼	Unit 10	820	1-67-34	30		48	24			20
		Sherack	811	1-45-54	44	78	59	31	1395	35	13
		Brenna	790	0-19-81	88	50	97	60	806	17	5
		Falconer	750	8-52-36	34	100	40	18	937		4
		Unit A	724	45-50- 5	20					108	

Appendix A—Continued

Site No.	Location Twp.-Range-Section	Unit	Elevation of Top (in feet)	Sd-St-Cl	W%	γ_D	LL	PI	q_u	C_I	SPT
29-35	153-51-36SW¼NE¼SW¼	Unit 10	823	2-70-28	31						10
		Sherack	818	3-36-63	55	71	62	33	1216	33	5
		Brenna	786	1-14-85	76	55	96	62	1052	32	6
		Brenna Transition	740	2-27-70	72	72	70	41	1036	34	6
		Falconer	732	20-38-35	24	103	37	20	1604	62	13
		Wylie	706		50	84	40	22	1597	61	11
		Unit A	687	28-40-24	14		35	17		97	
29-37	152-50-18SE¼NW¼SW¼	Unit 10	827	8-62-30	29	90	40	15	1595	64	15
		Sherack	821	4-32-63	46	78	54	26	1408	50	6
		Harwood	788	3-18-80	42	78	68	35	1963	77	10
		Brenna	785	1- 4-95	67	60	84	46	1237	39	4
		Brenna Transition	748	4-20-77							4
		Falconer	742	22-30-42	27	97	36	18	1664	49	11
		Wylie	715	13-14-72	41					70	12
		Unit A	690	38-30-23	12		23	10		113	
29-38	152-50-31SE¼NW¼NE¼	Unit 10	833	3-84-14	25	88	32	8	1096	54	7
		Sherack	825	2-36-62	46	74	56	26	1460	39	5
		Harwood	795	2-16-82	40	80	66	32	2246	81	9
		Brenna	788	2- 9-90	71	59	78	40	1007	38	4
		Falconer	760	17-39-11	26	97	39	18	1934	73	11
		Wylie	715	6-41-54	39	75	56	26	2236	59	12
		Unit A	700	42-34-19	12		22	8		147	
29-39	151-50-6NE¼NE¼NW¼	Unit 10	833								
		Sherack	828	4-45-51	46	78	49	21	1676	65	5
		Harwood	798	0-13-86	48	75	78	40	1987	78	8
		Brenna	791	1-14-85	76	55	85	44	1070	43	4
		Falconer	758	18-40-40	28	97	40	18	1578	69	12
		Wylie	713	6-12-82	50		39	15		40	10
		Unit A	703	65-20- 9	11		20	6		143	
29-39.5	151-50-6SE¼NW¼SE¼	Unit 10	834	1-78-21							
		Sherack	827	1-44-56							
		Brenna	792	0-14-86							
		Falconer	760	15-42-42							
		Wylie	715	1-17-81							
		Unit A	703	56-38- 7							
29-40	151-50-7NE¼NE¼NW¼	Unit 10	834	7-68-24	32	92	33	10	1498	20	6
		Sherack	828	5-47-49	43	80	47	18	1970	43	6
		Brenna	793	1-10-88	71	58	83	42	1025	37	4
		Falconer	761	18-39-44	29	94	48	20	1720	75	8
		Wylie	715	4-40-55	50	81	52	26	2841	31	11
		Unit A	703	29-47-16	13		25	10		90	
29-41	151-50-18NE¼NE¼NW¼	Unit 10	837	0-83-11	26		33	8		62	10
		Sherack	828	2-41-58	44	78	53	26	1712	45	11
		Harwood	806	1-16-83	41	79	75	40	2242	85	21
29-42	151-50-19NE¼NE¼NE¼	Unit 10	838	5-79-18	32	94	33	9	1550	34	8
		Sherack	829	3-41-56	42	77	54	26	1635	52	6
		Harwood	806	0-11-88	39	81	76	41	2547	83	12
		Brenna	800	1-11-88	72	58	97	59	1134	42	4
		Falconer	771	16-38-43	27	98	39	27	1748	61	12
		Wylie	723	4-14-81	47	71	76	45	2625	44	11
		Unit A	702	40-31-20	10		22	8		142	

Appendix A—Continued

Site No.	Location Twp.-Range-Section	Unit	Elevation of Top (in feet)	Sd-St-Cl	W%	γ_D	LL	PI	q_u	C_I	SPT
29-43	151-50-32SW¼SW¼SW¼	Unit 10	844		30	89	36	12	882	29	17
		Sherack	836		40	81	51	24	2075	49	12
		Harwood	816		44	77	80	44	2064	73	18
		Brenna	810		67	60	99	60	1095	54	6
		Falconer	793		27	98	40	19	1547	68	12
		Wylie	738		48	74	58	30	1841	43	11
		Unit A	725		17		27	9		126	
29-44	150-50-5	Unit 10	844	9-53-38	26						7
		Sherack	837	7-58-35	35	82	40	14	2016	43	6
		Brenna	800	1-6-93	64	57	63	20	1113	50	5
		Falconer	795	17-28-54	29		42	19			10
		Wylie	738	9-18-71	44		50	22			9
		Unit A	694								
29-45	150-50-8SW¼SE¼SE¼	Unit 10	850	1-84-15	27	87	32	7	212	61	11
		Sherack	842	2-43-55	41	80	54	24	1963	50	8
		Harwood	822	1-17-82	49	71	77	41	1639	78	13
		Brenna	816	0-13-86	71	58	90	53	966	38	7
		Brenna Transition	800	2-30-69	47	74	67	34	1722	46	8
		Falconer	796	17-42-37	28	97	39	19	1588	62	11
		Unit A	730	51-18-10	14		21	6		135	
29-47	150-50-29SW¼	Unit 10	859	2-82-16	23	96	32	8	1744	39	15
		Sherack	849	2-49-49	40	81	48	20	2275	53	12
		Brenna	831	0-23-77	72	57	95	57	1098	54	7
		Falconer	820	12-37-48	34	89	44	22	1483	54	12
		Unit A	750	48-28-14	15		22	8		132	
29-49	149-50-8SW¼SE¼SE¼	Sherack	865	2-71-27	40	79	39	11	1254	23	8
		Falconer	851	18-49-32	28	96	37	17	1877	62	12
		Unit A	770	35-34-25	18		30	12	118		
29-50	149-50-32SW¼SW¼SE¼	Unit 10	891	65-28- 7	11						9
		Sherack	884	19-69-12	24		27	4		75	10
		Falconer	880	13-40-45	30	93	44	20	2797	74	14
		Unit A	795	50-24-23	19		31	11		115	
29-51	148-50-7SW¼SE¼SE¼	Unit 10	911	55-30-14	18		33	9			19
		Sherack	905	4-74-21	31	91	34	9	1601	52	12
		Falconer	895	15-44-39	31	92	42	18	1704	63	10
		Wylie	810	6-12-74	38		62	33		74	13
		Unit A	800	40-38-16	24		34	9		96	
29-52	148-50-31NW¼NE¼NE¼	Unit 10	919	55-30-14	22		27	7			23
		Upper Sherack	916	8-88- 4	26						10
		Lower Sherack	913	24-42-34	27	96	25	4	1788	35	12
		Falconer	909	12-37-48	32	89	48	24	2297	68	14
		Unit A	808	34-37-24	19		31	11		115	
29-53	147-50-6SW¼SE¼SE¼	Sherack	919	34-34-28	28	94	53	28	2736	85	21
		Falconer	915	12-33-54	34	88	48	24	2509	61	12
		Wylie	837	4-20-71	50	67	73	42	831	42	7
		Unit A	826	41-32-18	20	95	31	10	1237	114	
29-54	147-50-18SW¼SE¼SE¼	Upper Sherack	933	18-72- 9	28		26	4			20
		Lower Sherack	925	7-32-61	37	85	65	38	2726	78	18

Appendix A—Continued

Site No.	Location Twp.-Range-Section	Unit	Elevation of Top (in feet)	Sd-St-Cl	W%	γ_D	LL	PI	q_u	C_I	SPT
29-54	147-50-18SW¼SE¼SE¼	Huot	920	6-29-65	46	75	66	31	1223	40	7
		Falconer	880	10-32-56	49	73	64	34	1122	38	7
		Wylie	849		60	66	70	34		15	7
		Unit A-1*	835	5-74-19	27	92	28	6	3205	136	34
		Unit A	828	34-38-18	20	91	31	10	2726		
29-55	147-50-30SW¼SW¼SE¼	Unit 10	934	3-83-13	38		33	5		39	8
		Sherack	928	6-43-50	44	76	36	12	794		6
		Huot	918	2-18-80	58	66	62	32	855	14	3
		Unit A-1*	860	14-80-6	23	97	28	4	3015	45	38
		Unit A	840	52-28-10	17		25	7		109	
29-56	146-50-6NW¼NW¼NE¼	Unit 10	932	30-58-12	23	71	27	5			15
		Sherack	925	2-87-11	34	70	35	6			12
		Huot	915	0-19-81	63	63	65	35	928	38	3
		Unit A-1*	853	2-78-20	33	85	30	6	2292	65	26
		Unit A	841	39-33-18	17		25	7		109	
29-57	146-50-18SE¼SE¼SW¼	Unit 10	908		35		51	26			8
		Sherack	904	4-60-36	47	76	82	48	1773	76	10
		Brenna	898	0-23-76	50	71	69	37	2538	36	6
		Huot	856	6-31-61	37	86		8	1638	98	8
		Unit A	837	33-41-16	17		26	10		100	
29-59	145-50-6NE¼NW¼NW¼	Unit 10	891	19-57-23	31	90	35	12	1596		10
		Unit A-1*	857	4-78-18	38	87	51	22	2267		18
		Unit A	841	28-44-21	21	102	31	12	2667	113	
29-60	145-50-6NE¼SE¼SW¼	Unit 10	909		33						42
		Sherack	902	0-26-74	50	74	72	40	3065	62	13
		Brenna	880	0- 9-91	55	66	93	59	2562	52	6
		Argusville	869	9-33-58	39	84	55	30		53	
		Unit A-1*	858	1-92- 7	28	95	28	3	3592	109	84
29-62	145-50-20SE¼SE¼SE¼	Unit 10	903		32						32
		Sherack	898	3-29-68	43	78	75	44	1446	62	19
		Brenna	874	2-23-75	50	74	65	33	1582	58	14
		Argusville	863	4-26-68	56	80	57	34	1858	45	9
		Unit A	835	28-39-26	18	90	24	9	4148	99	
29-63	145-50-33SW¼SW¼SW¼	Unit 10	895	13-39-48	43	76	73	43	2151	65	12
		Sherack	891	2-31-67	46	75	67	34	2686	56	10
		Brenna	864	0-32-68	54	73	66	35	1461	58	9
		Argusville	850	4-18-77	48	70	78	47	2564	52	
		Unit A	835	29-41-22	19	109	31	12	2991	104	
29-64	144-50-5SE¼SE¼SE¼	Unit 10	898	6-32-55	29		76	44			29
		Sherack	890	3-30-68	45	75	75	41	2056	69	16
		Brenna	860	0-16-84	50	74	63	30	2390	58	10
		Argusville	850	2-20-78	53	74	70	39	2404	53	9
		Unit A	830	21-43-31	26	92	28	12	3000	75	
29-65	144-50-20NE¼NW¼NW¼	Unit 10	897		35						25
		Sherack	888	1-17-82	44	77	77	44	2233		22
		Brenna	865	0-15-85	52	71	70	37	1894	55	10
		Argusville	847	5-22-74	35	85	45	22	2993		
		Unit A	834	40-30-15	18	105	28	10	2726	93	
29-66	144-50-33SE¼NW¼SE¼	Unit 10	876	7-33-60	41	80	64	30	1476	74	13
		Sherack	864	0-10-89	51	72	64	32	1141	55	6
		Brenna	862	1-23-76	57	67	66	36	882	40	7
		Argusville	841	3-29-68	53	67	79	40	1705	50	6
		Unit A	830	35-40-18	19	112	32	10	5801	95	

Appendix A—Continued

Site No.	Location Twp.-Range-Section	Unit	Elevation of Top (in feet)	Sd-St-Cl	W%	γ_D	LL	PI	q_u	C_I	SPT
29-67	144-50-33SE¼SW¼SE¼	Unit 10	897		32					90	25
		Sherack	892	1-17-82	45	75	69	36	2182	63	16
		Brenna	868	0-15-85	51	71	68	35	2258	48	9
		Argusville	847	5-22-74	49	73	61	32	1737	47	8
		Unit A	825	40-30-15							
29-68	143-50-15SE¼NE¼SW¼	Unit 10	895		35						22
		Sherack	888	1-21-78	45	78	78	44	2643	68	21
		Brenna	862	0-14-87	49	72	72	38	2622	57	13
		Argusville	844	3-22-74	51	72	80	44	2101	43	12
		Unit A	820	35-36-20	23		24	8		147	
29-70	142-50-2NW¼NE¼NE¼	Unit 10	891		32						19
		Sherack	885	2-14-84	42	77	74	40	2406	76	18
		Brenna	866	0-15-85	50	76	71	38	2411	58	11
		Argusville	832	3-20-76	48	77	56	27	2264	51	10
		Unit A	822	39-38-16	16	115	22	6	8814	114	
29-72	142-50-24NW¼NE¼NW¼	Unit 10	889	1-26-72	34	90	72	43	2368		18
		Sherack	882	1- 9-90	48	74	76	43	2150	71	14
		Brenna	860	0-12-88	51	70	73	46	2258	61	13
		Argusville	830	2-17-81	51	71	70	38	2299	50	12
		Unit A	820	37-36-17	16		29	8	4236	153	
29-73	141-49-6SW¼SW¼SW¼	Unit 10	886	1-26-70	32	91	67	37	3436	85	26
		Sherack	876	0- 9-90	50	71	90	53	1712	77	9
		Brenna	863	0- 9-89	53	68	82	44	2315	61	9
		Argusville	829	2-14-84	50	72	71	41	2298	58	9
		Unit A	818	35-34-22	16	87	27	10	2352	106	
29-74	141-49-28NW¼SW¼	Unit 10	890	2-32-66	30	93	62	33	4154	90	29
		Sherack	882	1-23-75	38	82	69	38	1910	86	13
		Harwood	874	0- 6-93	46	74	92	52	1751	80	14
		Brenna	868	0- 8-90	58	65	89	51	2043	57	6
		Argusville	835	2-13-84	54	69	78	44	2058	56	6
		Unit A	821	36-30-18	16	81	26	10	2341	86	
29-75	141-49-28NW¼SW¼SE¼	Unit 10	888		26	95	58	32		103	34
		Sherack	882	1-32-66	28	98	65	38	2233	98	16
		Harwood	876	0-13-87	54	69	96	57	1758	70	14
		Brenna	868	0-14-86	60	69	88	53	1540	57	7
		Argusville	829	3-18-79	56	68	85	50	1838	56	8
		Unit A	819	37-33-18	16		26	10			
29-77	141-49-33SE¼SE¼SE¼	Unit 10	893	1-24-75	31	92	69	40	4922	91	30
		Sherack	886	3-21-76	43	78	66	37	1952	60	16
		West Fargo	877	56-26-16	29	81	32	11	1222	94	27
		Harwood	871	1- 9-90	50	73	89	49	1621	83	14
		Brenna	866	0- 5-95	69	59	85	49	1415	34	5
		Argusville	833	5-17-79	52	71	67	39	1688	41	6
		Unit A	812	44-27-11	15		20	5		121	
29-79	140-49-15SW¼SE¼SW¼	Unit 10	894	1-32-67	30	90	59	32	2572	92	25
		Sherack	886	0-28-71	43	80	61	32	2149	62	16
		Brenna	869	0- 6-94	65	60	90	52	1456	45	6
		Argusville	824	4-17-79	54	69	67	39	2044	50	7
		Unit A	803	29-33-26	17		36	16		112	
29-80	140-49-27SE¼SE¼SE¼	Unit 10	896		28	91	58	30	3148	97	24
		Upper Sherack	891	2-31-68	42	80	61	39	2525	64	13

Appendix A—Continued

Site No.	Location Twp.-Range-Section	Unit	Elevation of Top (in feet)	Sd-St-Cl	W%	γ_D	LL	PI	q_u	C_I	SPT
29-80	140-49-27SE¼SE¼SE¼	Lower Sherack	881	0-76-24	42	29	8				
		West Fargo	878	77-22- 1	22						28
		Brenna	868		68	58	86	41	1329	36	6
		Argusville	840	2-11-87	63	62	85	39	1375	58	7
		Unit A	804	25-38-24	15		34	14		132	
29-81	140-49-34SE¼NE¼NE¼	Unit 10	898	1-37-61	30	94	62	33	3474	70	23
		Sherack	894	1-31-68	42	79	63	32	1948	74	14
		West Fargo	879	82-15- 2							40
		Harwood	873		76				891		11
		Brenna	866	0-11-89	69	59	93	50	1304	49	4
		Argusville	830	3-19-78	51	70	75	40	1642	62	7
		Unit A	801	40-41-17	16		19	7		158	
29-82	140-49-34SE¼SE¼SE¼	Unit 10	899	1-32-67	27	93	60	27	1365		
		Sherack	891	2-29-69	41	80	62	29	1897	64	14
		West Fargo	880	62-29- 8	29	95	22	5	3980	120	30
		Harwood	872	1-47-53	42	79	46	15	1303	33	13
		Brenna	870	0-10-89	69	59	89	44	1350	51	5
		Argusville	832	3-23-74	51	70	65	34	1996	48	7
		Unit A	802	33-34-21	14		23	7		122	
29-83	139-49-3NE¼SE¼SE¼	Unit 10	899								
		Sherack	896	2-29-69	40	80	61	30	2285	61	14
		West		82-12-6							
		Fargo	885	3-68-29	31	86	39	13	1498	34	30
		Harwood	874	0- 9-91	44	76	93	50	1930	90	13
		Brenna	872	1-13-86	63	61	91	50	1276	53	6
		Argusville	832	3-21-76	50	71	70	39	1676	51	6
		Unit A	804	39-33-18	17		27	10		126	
29-84	139-49-3SE¼SE¼	Unit 10	900		32	86	64	33	1706	88	18
		Sherack	896	1-28-71	40	82	65	33	2085	72	13
		West Fargo	884	54-35- 9	24		27	6	1522		25
		Harwood	876	1-17-82	43	78	74	37	1856	77	12
		Brenna	874	1- 6-94	65	62	87	46	1217	47	6
		Argusville	834	3-17-80	53	71	70	37	1855	54	6
		Unit A	808	38-30-16	19		27	9	2277	128	
29-85	139-49-3SE¼SE¼SE¼	Unit 10	900	3-31-67	35		80	48	1982	94	
		Sherack	896	0-26-72	43	77	62	34	1935	66	14
		West		49-37-14							
		Fargo	884	1-58-40	40	80	43	17	1498	91	28
		Harwood	876	0- 8-92	50	74	84	44	2042	76	16
		Brenna	874	0- 7-93	67	80	90	51	1357	44	6
		Argusville	834	4-17-79	51	70	68	37	2283	52	6
		Unit A	808	39-33-17	20		21	10		110	
29-86	139-49-11NW¼NW¼NW¼	Unit 10	904		28						32
		Sherack	899	2-34-64	41	81	53	27	2295	50	17
		West Fargo	886	28-58-14	34	28	6				21
		Brenna	860	0-10-90	60	64	85	48	1643	52	8
		Argusville	831	3-17-79	53	71	69	38	2154	51	10
		Unit A	811	28-33-15	16		32	12		134	

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Site No.	Location Twp.-Range-Section	Unit	Elevation of Top (in feet)	Sd-St-Cl	W%	γ_D	LL	PI	q_u	C_I	SPT
29-87	139-49-11SW¼SW¼SW¼	Unit 10	904		32						19
		Sherack West	899	3-34-64	40	81	65	36	2643	71	18
		Fargo	886	60-33-10	31		32	8		62	22
		Brenna	843	1-10-89	58	67	84	47	1690	50	6
		Argusville	830	4-20-76	48	74	67	36	1956	55	8
		Unit A	811	57-20- 8	22		30	7		179	
29-88	139-49-23SW¼SW¼SW¼	Unit 10	905	1-50-49	28		60	33			24
		Sherack	900	1-38-62	43	78	71	44	1338	56	16
		Brenna	884	0-22-78	62	64	80	57	1467	47	4
		Argusville	850	4-30-66	51	72	68	40	1683	49	6
		Unit A	830	38-34-10	15	116	23	7	2366	80	
29-89	139-49-26SW¼SW¼	Unit 10	898	1-29-70	34	79	69	45	2139		17
		Sherack	892		43		72	40			
		Brenna	890	0-17-83	59	66	86	54	1316	52	6
		Argusville	847	3-22-74	50	70	70	44	1578	40	7
		Unit A	828	36-30-11	14		22	6			
29-90	138-49-23SW¼SW¼SW¼	Unit 10	908	1-35-64	30		68	44			26
		Sherack	903	1-17-82	43	75	92	60	1361	78	20
		Brenna	888	0-19-81	46	76	78	45	2601	65	8
		Argusville	858	5-25-70	43	77	71	44	2302	58	10
		Unit A	836	34-38-13	14	120	23	8	4817	144	
29-91	138-49-35SW¼SW¼SE¼	Unit 10	913	1-20-79	28		75	44			32
		Sherack	907	1-14-86	41	75	88	58	1475	71	26
		Brenna	893	0-17-83	45	77	72	43	2524	57	8
		Argusville	859	4-21-75	42	78	64	37	2652	54	9
		Unit A	839	48-33-11	27	112	22	7	1290	170	
29-92	137-49-2NW¼SE¼	Unit 10	909	2-42-56	29	88	59	33	2270	81	23
		Brenna	892	0-27-73	45	71	61	33	2278	55	7
		Argusville	861	6-24-70	45	85	63	38	2546	46	8
		Unit A	838	40-32-16	13		22	8		118	
29-93	137-49-23SW¼SE¼SE¼	Unit 10	920	2-35-63	32	83	65	36	1657	75	25
		Upper Sherack	912	1-23-76	40	80	69	43	2438	65	11
		Lower Sherack	894	1-30-66	42	81	62	36	2930	36	9
		Brenna	888	1-41-58	43	79	48	24	2118	37	7
		Argusville	870	3-25-72	41	80	52	24	2904	51	7
		Unit A	853	44-31-12	17	115	22	7	4648	95	
29-94	136-49-3NE¼NE¼NE¼	Unit 10	925	4-32-63	26		58	33			24
		Upper Sherack	916	0-25-74	40	82	70	44	2086	58	9
		Lower Sherack	893		39	82	57	34	2564	50	10
		Brenna	886	0-38-62	42	79	50	26	2244	47	10
		Argusville	874	4-26-70	42	82	60	37	2904	54	11
		Unit A	850	45-27-14	10		19	6		142	
29-95	136-49-22SE¼SE¼SE¼	Unit 10	928	2-28-70	32		67	39			35
		Upper Sherack	918	1-35-64	41	82	55	35	1928	44	6
		Lower Sherack	907	1-59-40	33	90	38	14	3372	38	9

Appendix A—Continued

Site No.	Location Twp.-Range-Section	Unit	Elevation of Top (in feet)	Sd-St-Cl	W%	γ_D	LL	PI	q_u	C_I	SPT
29-95	136-49-22SE¼SE¼SE¼	Argusville	897	4-37-59	39	81	53	30	2502	46	6
		Unit B	866	27-42-26	16		30	14		106	
29-96	136-49-34SE¼SE¼SW¼	Unit 10	932	2-22-75	32	78	67	39			26
		Upper Sherack	923	2-36-64	36	86	60	37	2090	65	10
		Lower Sherack	909		34	87	40	17	2184	27	9
		Argusville	899	3-30-67	42	79	57	32	2380	43	5
		Unit B	877	39-29-19	11	114	21	7	2507	71	
29-96.5	136-49-34SE¼SE¼SW¼	Unit 10	932	2-22-75	30	90	55	31	1792	79	17
		Upper Sherack	923	2-36-64	42	81	64	40	2082	55	6
		Lower Sherack	909		31		32	13			
		Argusville	899	3-30-67	46	77	55	29	2198	30	4
		Unit B	877	38-29-19	16	117	23	8		85	
29-97	135-49-15SW¼SE¼SE¼	Unit 10	938	5-54-41	28		48	24			17
		Upper Sherack	930	0-41-58	37	85	51	28	2611	48	8
		Lower Sherack	920	0-34-66	40	81	54	29	2331	49	7
		Argusville	910	6-24-71	40	83	56	32	2296	27	7
		Unit B	900	30-36-26	20	109	29	13	2025	58	
		Unit D	888	41-32-14	12	112	20	5	2334	67	
29-98	135-49-27SW¼SE¼SE¼	Unit 10	944	3-42-56	28		54	31			36
		Sherack	936	3-67-31	37	88	49	26	2938	59	11
		Argusville	920	1-35-64	45	79	53	27	1977	40	5
		Unit B	906	33-32-20	22	109	28	12	1922	50	
		Unit D-1*	891	63-25- 8	16		22	6		94	
29-99	134-49-10SW¼SE¼SE¼	Unit 10	949	29-51-20	32	85	58	34	1167	73	22
		Sherack	943	2-35-64	43	80	59	33	2228	48	7
		Argusville	911	2-31-67	38	78	55	31	1736	34	6
		Unit B	899	27-30-36	26	101	34	16	3756	60	
		Unit C	886	14-31-54	43	71	50	26		74	
		Unit D	884	40-37-11	11		18	3			
29-100	134-49-15SW¼SE¼SE¼	Unit 10	951	54-34-12	34		60	35			20
		Sherack	946	1-33-66	42	80	61	36	1557	50	6
		Argusville	913	6-30-64	40	82	49	25	1779	39	4
		Unit B	905	27-34-35	25	102	35	17	1561	52	
		Unit D	890	35-36-17	16	116	24	11	6169	102	
29-102	133-49-22SW¼NW¼	Unit 10	973	69-23- 8	12						16
		Sherack	961	1-35-66	47	75	72	45	1134	48	9
		Argusville	921	6-37-56	41	84	42	16	1347	46	7
		Unit B	901	24-36-35	25	101	36	17	1400	46	
		Unit C	874	1-34-64	45	78	54	29	2004	26	11
		Unit D	871	32-39-19	16	114	26	10		90	
29-103	132-49-4NE¼	Unit 10	963	3-27-70	33		69	43			
		Sherack	956	1-35-65	42	82	59	33	2277	62	9
		Argusville	922	2-46-52	44	80	52	26	1852	29	8
		Unit B	912	26-38-31	28	99	38	18	1558	60	
		Unit C	880	0-31-68	50	76	63	35	1864	47	10
		Unit D	873	34-37-17	15	123	28	12		100	

Appendix A—Continued

Site No.	Location Twp.-Range-Section	Unit	Elevation of Top (in feet)	Sd-St-Cl	W%	γ_D	LL	PI	q_u	C_I	SPT
29-104	132-49-9NE¼NW¼NW¼	Unit 10	964	4-70-26	26		40	17			9
		Sherack	952	2-32-68	44	76	60	35	1022	40	5
		Argusville	922	2-24-74	56	72	50	27	1379	11	4
		Unit B	910	29-34-29	26	99	36	17	1963	56	
		Unit C	878	2-33-63	45	77	54	28	1981	36	14
		Unit D	875	32-37-25	15		29	12		111	
29-105	132-49-9NW¼SE¼SE¼	Unit 10	965	6-57-36	26		54	32			17
		Sherack	952	1-25-74	40	81	59	32	1808	54	13
		Argusville	922	4-33-62	44	79	55	31	2069	38	7
		Unit B	909	27-37-29	26	101	38	18	2939	72	
		Unit C	878	0-23-76	45	83	52	25	2551	47	8
		Unit D	875	39-26-21	15		29	11			
29-106.5	132-49-28NE¼NW¼NW¼	Unit 10	967	1-24-75	30		64	39			29
		Sherack	958	1-28-72	39	86	64	38	2936	72	9
		Argusville	943	1-38-61	39	83	50	24	2369	44	
		Unit B	917	19-36-41	29	98	40	18	3565	68	
		Unit C	888	2-29-69	38	81	59	29	4295	70	27
		Unit D	867	31-31-28	16		34	17		115	
29-107	131-49-4SW¼SE¼SE¼	Unit 10	974	8-38-54	26		54	32			18
		Sherack	968	2-33-66	34	88	60	36	2475	69	21
		Argusville	950	1-29-70	40	81	52	27	1798	45	8
		Unit B	928	30-32-30	27	97	39	18	3342	61	26
		Unit C	900	3-35-60	41	80	50	24	2663	42	14
		Unit D	887	26-45-26	14	113	27	11	1955	100	
29-108	131-49-16SE¼SW¼SW¼	Unit 10	978	1-22-78	18		64	42			13
		Sherack	972	2-31-67	40	85	61	39	2422	64	10
		Argusville	952	2-36-61	42	80	50	26	2020	43	6
		Unit B	922	26-35-33	24	101	34	16	3122	56	
		Unit C	894		40						14
		Unit D	889	36-36-17	8		18	7		166	
29-109	131-49-21SE¼SW¼SW¼	Unit 10	979	38-35-27	25		48	28			17
		Sherack	971	2-29-70	41	81	62	38	2138	52	8
		Argusville	958	1-28-65	42	82	48	22	1869	43	5
		Unit B	930	22-40-35	26	96	39	20	1659	70	
		Unit C	906	3-26-69	39	80	52	26	1876	35	9
		Unit D	898	59-16- 4	76		22	10		54	
29-110	131-49-28SE¼SW¼SW¼	Unit 10	986	11-32-56	30		62	36			25
		Sherack	980	2-27-72	35	88	47	22	2688	66	16
		Argusville	965	7-69-23	32	98	36	9	1536	89	8
		Unit B	954	29-35-32	29	94	39	17	2036	55	
		Unit C	907	3-24-72	45	79	56	31	1581	45	14
		Unit D	894	34-38-22	12		21	7			
29-111	130-49-9NW¼NE¼NE¼	Unit 10	1018	19-69-12	27	88	31	4	1604		10
		Sherack	1006	31-59-10	27	98	36	16	2543		23
		Unit B	990	30-28-27	26	97	38	18	2531	56	
		Unit C	910	3-40-56	23	100	45	23	2168	101	
		Unit D	894	55-22- 6	12						
29-112	130-49-21NW¼NW¼NE¼	Unit 10	1033	60-28-12	16		30	6			12
		Sherack	1027	19-70-12	30	92	29	9	1982		12
		Unit B	993	26-39-28	26	99	36	16	2246	61	17
		Unit C	940	3-41-57							
		Unit D	933	40-34-15	12		19	7		104	

Appendix A–Continued

Site No.	Location Twp.-Range-Section	Unit	Elevation of Top (in feet)	Sd-St-Cl	W%	γ_D	LL	PI	q_u	C_I	SPT
29-113	130-49-28NW¼NE¼NE¼	Unit 10	1048	64-26- 9	13						22
		Sherack	1040	5-85-10	32	91	31	6	1953	52	9
		Unit B	994	24-41-27	26		32	10	828		
		Unit D	935	37-36-16	11		27	11		118	
29-114	129-49-9SW¼SE¼SE¼	Unit 10	1086	72-20- 8	10						9
		Sherack	1077	25-69- 6	28				1600		34
		Unit B	981	26-39-30	23	104	36	16	4343	75	
		Unit D	968	36-35-19	13		25	8		131	
29-115	129-49-21SW¼SE¼SE¼	Unit 10	1084	12-68-20	24		34	10		59	15
		Sherack	1080	10-76-13	31	83	34	9	1505		22
		Unit B	1040	24-41-30	24	102	34	14	3623	71	
		Unit D	992	30-56-10	19						
29-116	129-49-33SW¼SW¼SW¼	Unit 10	1097	42-44-14	20		31	8			20
		Sherack	1093	9-76-15	24		27	3			18
		Unit B	1070	24-43-34	24	102	35	15	3279	80	
		Unit D	1014	29-44-25	18	115	28	12		110	

APPENDIX B

DESCRIPTIONS OF SELECTED TESTHOLES

Traill County
T-12

Location: T.148N., R. 49W., sec. 33SE¼SE¼SW¼
Elevation: 865 Feet

Depth in Feet		Description
0-9	Unit 10	Road fill.
9-14	Sherack Fm.	Clay silt; mottled; brownish gray; iron stained; laminated; moderately soft, slightly plastic.
14-19	Sherack Fm. & Poplar River Fm.	Clay silt; yellowish brown; marbled; laminated; overlies gray laminated silt, organic laminae.
19-24	Poplar River Fm.	Peat, organic silt, wood fragments; overlies pebbly silty clay, alluvium(?).
24-39	Huot Fm.	Clay; gray; stiff to very stiff; pebbles.

T-15

Location: T. 147 N., R. 49 W., sec. 49SW¼SW¼SW¼
Elevation: 870 Feet

Depth in Feet		Description
0-7	Sherack Fm.	Clay; silty; reddish brown to grayish brown; laminated; oxidized; iron nodules.
7-10	Poplar River Fm.	Sand; gravelly, clayey; moderately well sorted.
10-24	Huot Fm.	Clay; gray; abundant soft CO_3 nodules, pebbles; moderately stiff to very stiff, plastic.

T-18

Location: T. 147 N., R. 49 W., sec. 11SW¼SW¼SW¼
Elevation: 865 Feet

Depth in Feet		Description
0-3	Unit 10	Clay; gray to black; abundant organics.
3-9	Sherack Fm.	Clay; silty; yellowish brown to gray; soft CO_3 nodules; laminated; some coarse sand near base.
9-14	Poplar River Fm. & Huot Fm.	Clay; gray; mealy; slickensides; very hard; stones; unbedded with depth.

T-19

Location: T. 147 N., R. 49 W., sec. 10NW¼NE¼NW¼
Elevation: 870 Feet

Depth in Feet		Description
0-9	Unit 10	Fill.
9-14	Sherack Fm. & Poplar River Fm.	Silt, clay, clayey silt; yellowish brown to gray; laminated; thick silt beds near base; gravelly.
14-19	Poplar River Fm. & Huot Fm.	Clay; gray; mealy, brittle, very stiff; unbedded and stony with depth.

T-20

Location: T. 147 N., R. 49 W., sec. 10NW¼NW¼NW¼
Elevation: 868 Feet

Depth in Feet		Description
0-4	Unit 10	Fill.
4-9	Unit 10 & Sherack Fm.	Fill; clay; silty; laminated; oxidized; iron nodules.
9-14	Poplar River Fm. Huot Fm.	Sand; coarse, gravelly, clay; mealy; gray; slickensides; pebbles.

T-21

Location: T. 147 N., R. 49 W., sec. 15SW¼NW¼SW¼
Elevation: 865 Feet

Depth in Feet		Description
0-4	Unit 10 & Sherack Fm.	Fill; clay, silty; laminated; oxidized.
4-8	Sherack Fm.	Clay; silty, sandy; laminated.
8-14	Huot Fm.	Clay; gray; unbedded; slickensides; small pebbles; soft CO_3 nodules; stiff to very stiff.

T-22

Location: T. 147N., R. 49 W., sec. 22NE¼NE¼NE¼
Elevation: 865 Feet

Depth in Feet		Description
0-4	Unit 10	Fill; clay; yellowish brown; oxidized; weakly laminated; granular texture.
4-9	Sherack Fm.	Clay; silty; vaguely laminated; yellowish brown; soft CO_3 nodules; gypsum powder; moderately stiff; plastic.
9-14	Huot Fm.	Clay; gray; unbedded soft CO_3 nodules; stones; gypsum powder.

T-23

Location: T. 147N., R. 49 W., sec. 21SE¼SE¼SE¼
Elevation: 865 Feet

Depth in Feet		Description
0-1	Unit 10	Fill.
1-3	Sherack Fm.	Clay-silt, sand; laminated; oxidized.
3-4	Poplar River Fm.	Clay; gray; unbedded; mealy; very stiff.
4-14	Huot Fm.	Clay; yellowish brown to gray; iron nodules; soft CO_3 nodules; stones; unbedded; stiff; plastic.

T-24

Location: T. 147 N., R. 49 W., sec. 20SE¼SE¼SE¼
Elevation: 870 Feet

Depth in Feet		Description
0-8	Sherack Fm.	Silt; clayey; yellowish brown to gray; laminated; clayier with depth; plastic.
8-9	Poplar River Fm.	Sand; coarse.
9-14	Huot Fm.	Clay; gray; unbedded; gypsum powder; soft CO_3 nodules; pebbles; moderately stiff.

T-25

Location: T. 147 N., R. 49 W., sec. 20SW¼SW¼SW¼
Elevation: 875 Feet

Depth in Feet		Description
0-4	Unit 10	Silt, clayey silt; oxidized; granular texture; vague laminations.
4-8	Sherack Fm.	Clay; silty; yellowish brown; oxidized; laminated; iron nodules.
8-9	Poplar River Fm.	Sand; gravelly; poorly sorted.
9-14	Huot Fm.	Clay; yellowish brown to gray; unbedded; iron nodules; soft CO_3 nodules; gypsum powder; some pebbles; very stiff; moderately plastic.

T-27

Location: T. 147 N., R. 49 W., sec. 17SW¼SW¼SW¼
Elevation: 870 Feet

Depth in Feet		Description
0-8	Sherack Fm.	Clay; silty, oxidized; laminated; soft CO_3 nodules; iron nodules.

8-14	Huot Fm.	Clay; unbedded; soft CO_3 nodules; gypsum powder and nodules; pebbles; moderately stiff to stiff; plastic.

T-28

Location: T. 147 N., R. 49 W., sec. 4NE¼SW¼NE¼
Elevation: 865 Feet

Depth in Feet		Description
0-9	Sherack Fm.	Clay; silty; yellowish brown; iron nodules; vaguely laminated.
9-13	Poplar River Fm.	Silt; saturated; clay; mealy; unbedded.
13-19	Huot Fm.	Clay; gray; unbedded; some pebbles; soft to very stiff; plastic.

Walsh County

W-11

Location: T. 157 N., R. 53 W., sec. 33SW¼SW¼SW¼
Elevation: 845 Feet

Depth in Feet		Description
0-4	Unit 10	Clay, silt, soil, black to yellowish brown; oxidized.
4-19	Sherack Fm.	Clay; silty; reddish yellowish brown; vaguely laminated; gypsum crystals; iron nodules and stringers; soft CO_3 nodules.
19-24	Poplar River Fm. & Huot Fm.	Clay; gray; mealy; unbedded; clay; gray; unbedded; slickensides; very stiff.

W-12

Location: T. 157 N., R. 53 W., sec. 31NW¼NE¼NE¼
Elevation: 855 Feet

Depth in Feet		Description
0-4	Unit 10	Silt, very fine sand; dark yellowish brown; vaguely laminated; soft CO_3 nodules.
4-19	Sherack Fm.	Clay; silt; yellowish brown; laminated; soft CO_3 nodules; iron nodules and stringers; laminations more vague with depth; plastic.
19-24	Brenna Fm.	Clay; gray; soft CO_3 nodules; slickensides; very stiff; plastic.

W-13

Location: T. 157 N., R. 53 W., sec. 30SE¼SE¼SE¼
Elevation: 856 Feet

Depth in Feet		Description
0-6	Unit 10	Soil, silt, very fine sand; yellowish brown; granular texture.
6-19	Sherack Fm.	Clay; silt; yellowish brown; iron nodules; soft to moderately stiff.
19-29	Brenna Fm.	Clay; gray; unbedded; soft CO_3 nodules; slickensides; moderately stiff to very stiff; plastic.

W-14

Location: T. 157 N., R. 53 W., sec. 30NE¼NE¼NE¼
Elevation: 845 Feet

Depth in Feet		Description
0-4	Unit 10	Clay, silt; dark yellowish brown; unbedded to vaguely laminated; iron nodules; gypsum crystals; some pebbles.
4-14	Sherack Fm.	Clay, silt; reddish yellowish brown to grayish brown; oxidized; vaguely laminated; iron nodules; soft CO_3 nodules.
14-16	Poplar River Fm.	Silt; saturated; clay; mealy; unbedded; slickensides.
16-19	Brenna Fm.	Clay; gray; unbedded; abundant soft CO_3 nodules.

W-15

Location: T. 157 N., R. 53 W., sec. 28NW¼NW¼NW¼
Elevation: 844 Feet

Depth in Feet		Description
0-4	Unit 10	Clay-silt; reddish yellowish brown; iron and soft CO_3 nodules; unbedded to vaguely laminated.
4-17	Sherack Fm.	Clay-silt, reddish yellowish brown; oxidized; laminated; iron nodules; moderately stiff; plastic.
17-19	Poplar River Fm.	Clay; gray; mealy; soft CO_3 nodules; slickensides; very stiff; plastic.

W-16

Location: T. 157 N., R. 53 W., sec. 30NW¼NE¼NE¼
Elevation: 852 Feet

Depth in Feet		Description
0-4	Unit 10	Soil, clay-silt; dark yellowish brown to black; unbedded to vaguely laminated.

4-19	Sherack Fm.	Clay-silt; reddish brown to grayish brown; iron nodules and stringers; laminated.
19-24	Poplar River Fm.	No sample from upper 3 feet. Sand?, produces water; clay underneath; unbedded mealy; very stiff; plastic.

Pembina County

P-1

Location: T. 163 N., R. 53 W., sec. 16NW¼NE¼NE¼
Elevation: 820 Feet

Depth in Feet		Description
0-4	Unit 10	Soil, clayey silt; oxidized; laminated.
4-6	Brenna Fm.	Clay-silt; laminated.
6-24	Poplar River Fm.	Sand; fine to medium; grades to shale gravel with depth; mixed clay-silt; poor sample return.
24-34	Brenna Fm.	Clay; gray; unbedded.

P-2

Location: T. 163 N., R. 53 W., sec. 17NE¼SE¼SE¼
Elevation: 825 Feet

Depth in Feet		Description
0-4	Unit 10	Soil, clay-silt (alluvium).
5-13	Sherack Fm.	Clay-silt, silt, very fine sand near top of unit; oxidized; iron nodules; laminated.
13-19	Poplar River Fm.	Silt; clayey; gray; unbedded to thickly laminated; organic layers.
19-24	Brenna Fm.	Clay; drills hard.

P-3

Location: T. 163 N., R. 53 W., sec. 8SE¼NE¼NE¼
Elevation: 825 Feet

Depth in Feet		Description
0-9	Unit 10	Soil, clayey silt and sand; yellowish brown; oxidized; mottled; drills hard; disturbed laminations.
9-11	Sherack Fm. & Poplar River Fm.	Silt; clayey; laminated.
11-14	Poplar River Fm.	Silt, very fine sand; laminated.
14-24	Brenna Fm.	Clay; unbedded.

P-4

Location: T. 163 N., R. 53 W., sec. 17SE¼SE¼SE¼
Elevation: 825 Feet

Depth in Feet		Description
0-9	Unit 10	Soil, clayey silt; brown; no structure, saturated; looks like alluvium.
9-18	Poplar River Fm.(?)	Clayey sand and silt; dark brown to greenish gray with depth; abundant organic matter.
18-24	Brenna Fm.	Clay; yellowish brown; unbedded.

P-5

Location: T. 163 N., R. 53 W., sec. 9NW¼NW¼NW¼
Elevation: 825 Feet

Depth in Feet		Description
0-9	Unit 10	Soil, silt, sand; clayey; yellowish brown to dark brown.
9-14	Sherack Fm.	Clay, silt, very fine sand and silt; oxidized; laminated.
14-16	Poplar River Fm.	Fine sand; clayey with depth; saturated.
16-24	Brenna Fm.	Clay; gray.

P-6

Location: T. 163 N., R. 53 W., sec. 15SW¼NW¼NW¼
Elevation: 820 Feet

Depth in Feet		Description
0-10	Unit 10	Soil, clay-silt; grayish brown to gray; mottled; unbedded to laminated; soft CO_3 nodules.
10-14	Sherack Fm.	Clay; vaguely laminated.
14-17	Poplar River Fm.	Coarse sand; shaly; laminated silt.
17-24	Brenna Fm.	Clay; unbedded.

P-7

Location: T. 163 N., R. 53 W., sec. 22SW¼NW¼SW¼
Elevation: 820 Feet

Depth in Feet		Description
0-19	Sherack Fm.	Clayey silt; oxidized; iron nodules; soft CO_3 nodules; laminated; gray with depth; plastic.

P-9

Location: T. 163 N., R. 53 W., sec. 23SW¼NW¼NW¼
Elevation: 820 Feet

Depth in Feet		Description
0-9	Unit 10	Soil, clayey silt; granular texture, some parts laminated; abundant organics.
9-12	Sherack Fm.	Silt; clayey; laminated.
12-19	Poplar River Fm.	Silt; laminated; clayey in places.
19-24	Brenna Fm.	Clay; gray; slightly oxidized; unbedded.

P-10

Location: T. 163 N., R. 53 W., sec. 15NE¼SE¼NE¼
Elevation: 815 Feet

Depth in Feet		Description
0-5	Unit 10	Soil and alluvium.
5-14	Sherack Fm.	Clay; silty; oxidized; laminated.
14-19	Brenna Fm.	Clay; slightly oxidized in upper parts; unbedded; gypsum crystals; soft CO_3 nodules.

P-11

Location: T. 163 N., R. 53 W., sec. 2SE¼SE¼SE¼
Elevation: 815 Feet

Depth in Feet		Description
0-16	Unit 10	Fill, clay, silt; mottled; gypsum crystals; shell fragments; dispersed organics; granular texture; some parts laminated; sandy at base.
16-24	Brenna Fm.	Clay; gray; unbedded.

P-17

Location: T. 163 N., R. 53 W., sec. 14SE¼SE¼SE¼
Elevation: 810 Feet

Depth in Feet		Description
0-9	Unit 10	Soil, clay; brownish gray, granular structure; mottled.
9-14	Sherack Fm.	Clay-silt; grayish brown; oxidized; vaguely laminated; soft CO_3 nodules; organics near base.
14-25	Poplar River Fm.	Silt; laminated to unbedded; yellowish brown to gray; some organic debris near top.
25-34	Brenna Fm.	Clay; gray; oxidized near top; unbedded; plastic.

Cass County

N.D. State Highway Dept.
Structure I-29-68
Composite Boring 1, 2, 3

Location: T. 143 N., R. 50 W., sec. 15SE¼NE¼SW¼
Elevation: 896 Feet

Depth in Feet		Description
0-7	Unit 10	Clay, silt; brown to black; dispersed organics; oxidized.
7-30	Sherack Fm.	Clay; silty; grayish brown to light gray; laminated to vaguely laminated; lean to fat; soft white CO_3 pebbles; gypsum crystals.
30-50	Brenna Fm.	Clay; gray; unbedded to vaguely laminated; abundant soft CO_3 inclusions; gypsum crystals; lean to fat.
50-68	Argusville Fm.	Clay; silty; gray; contorted laminations; clay stringers; abundant sand pebbles; silty inclusions; gritty appearance.
68-101	Unit A	Pebble-loam; sandy; silty.

N.D. State Highway Dept.
Structure I-29-89
Boring 1

Location: T. 139 N., R. 49 W., sec. 26SW¼SW¼SW¼
Elevation: 903 Feet

Depth in Feet		Description
0-6	Unit 10	Clay, clay-silt; oxidized, gypsum crystals; mottled; granular texture.
6-10	Sherack Fm.	Clay, silt; oxidized; laminated.
10-55	Brenna Fm.	Clay; gray; some white calcareous specks; marbled lean and fat clay; contorted gray color banding near base.
55-73	Argusville Fm.	Clay; gray; clay stringers; sand grains; gritty appearance.
73-91	Unit A	Pebble-loam; silty; sandy.

N.D. State Highway Dept.
Structure I-29-89
Boring 2

Location: T. 139 N., R. 49 W., sec. 26SW¼SW¼SW¼
Elevation: 903 Feet

Depth in Feet		Description
0-8	Unit 10	Silt, clay; brown to black; granular texture; blocky structure; dispersed organics in the upper part.

8-10	Sherack Fm.	No samples.
10-55	Brenna Fm.	Clay; brownish gray to gray; mostly lean clay; some fat clay banding; vaguely laminated (?); mostly unbedded.
55-73	Argusville Fm.	Clay; gray; unbedded; clay stringers (marbled); silt pebble inclusions; gritty appearance.
73-96	Unit A	Pebble-loam; silty; sandy.

N.D. State Highway Dept.
Structure I-29-91
Boring 1

Location: T. 138 N., R. 49 W., sec. 35SW¼SW¼SE¼
Elevation: 913 Feet

Depth in Feet		Description
0-6	Unit 10	Clay; silty; black to yellowish gray; oxidized; granular texture; unbedded.
6-14	Sherack Fm.(?)	Clay; gray; unbedded; lean clay; clay stringers (marbled).
14-55	Brenna Fm.	Clay; yellowish brown to gray; mostly lean; only thin clay stringers; silty towards base.
55-75	Argusville Fm.	Clay; gray; lean; clay nodules; sand pebbles; silt pebble inclusions; gritty appearance.
75-97	Unit A	Pebble-loam; silty; sandy.

Richland County

N. D. State Highway Dept.
Structure I-29-105
Composite Borings 1, 2, 3

Location: T. 133 N., R. 49 W., sec. 9NE¼SW¼SW¼
Elevation: 966 Feet

Depth in Feet		Description
0-10	Unit 10	Silt, sand, clay; dark brown to black; dispersed organics; sand pebbles; oxidized; mottled.
10-45	Sherack Fm.	Clay, silt; oxidized in upper parts; gray; laminated to unbedded; mostly lean clay.
45-55	Argusville Fm.	Silt, clay; unbedded; parallel clay stringers (marbled); gritty appearance.
55-100	Unit B	Pebble-loam; silty; clayey inclusions near base.
100-115	Unit C	Clay; silty; laminated; clay stringers; silt balls; soft CO_3 nodules.
115-138	Unit D	Pebble-loam; sandy; sand and gravel in part; silty in part.

Clay County, Minnesota

F-2 Dormitory
Composite Borings 1, 2, 3

Location: T. 139 N., R. 48 W., sec. 8SE¼NE¼SE¼
Elevation: 907 Feet

Depth in Feet		Description
0-3	Unit 10	Clay; silty; very dark grayish brown; mottled; calcareous; unbedded to vaguely laminated.
3-15	Sherack Fm.	Clay; silty; dark grayish brown; oxidized; calcareous; laminated.
15-33	West Fargo Mbr.	Silt; clayey silt; very dark gray; laminated; some laminations contorted; organic laminae; thick bedded near base; peat.
33-40	Brenna Fm.	Clay; very dark gray; vaguely laminated; calcareous.

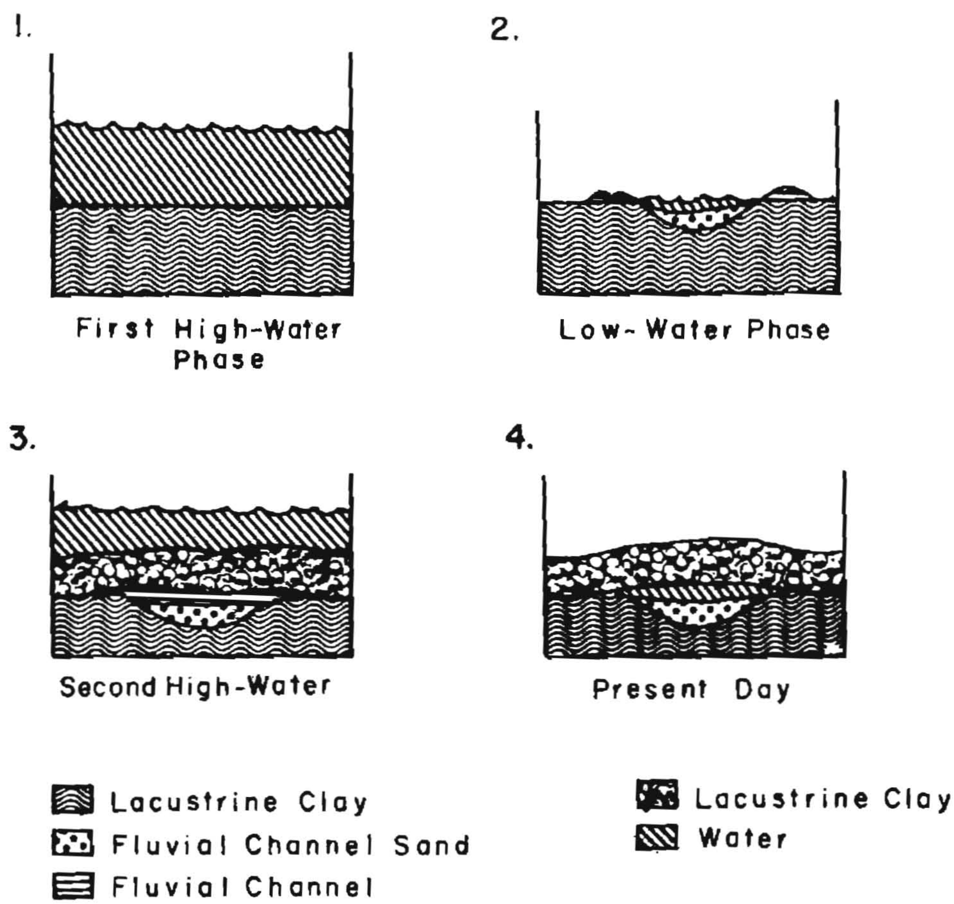

Figure 26. Formation of a compaction ridge.

APPENDIX C

Formation of Compaction Ridges

Compaction ridges are largely the result of differential compaction (fig. 26). The streams that cut their channels into the soft clay of the Brenna Formation and in the lower part of the Sherack Formation in some places were filled with coarser fluvial sediments. As the lake rose during the Emerson Phase, these channels were filled to the tops of their levees and subsequently buried by lacustrine silt and clay of the Sherack Formation. After the lake drained at the end of the Emerson Phase, modern streams began downcutting. The watertable was lowered below the ground surface, and the clay and silt which had been supported by pore water pressures added to the load being supported by the underlying clay. Both the sandy channel sediments and the underlying clay were consolidated by this increase in effective stress. However, compaction in the sand was much less than in the clay and caused a reversal in topography.

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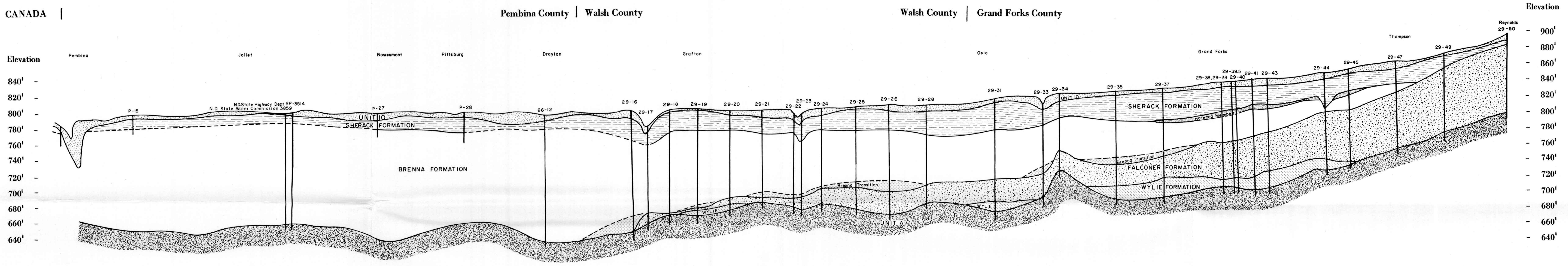
PLATE 1 CROSS SECTION SHOWING STRATIGRAPHY OF OFFSHORE SEDIMENT OF LAKE AGASSIZ IN THE RED RIVER VALLEY OF NORTH DAKOTA.



EXPLANATION

Lithostratigraphic and Other Units	Description	Origin	Age
UNIT 10	Silty clay, clayey silt, clay, silt, sand; yellowish brown-dark gray-black; granular texture, unbedded to weakly laminated; dispersed organic material	Alluvium; lacustrine sediment; fill	Holocene-Recent
SHERACK FORMATION	Clay, silty clay, clayey silt, silt; light brownish gray-gray; mottled, vague to distinct laminations; gypsum crystals common; moderately stiff to very stiff	Offshore lacustrine sediment	Holocene
BRENNA FORMATION	Clay, silty clay; grayish brown-very dark gray; vaguely laminated to unbedded; soft white and pink calcareous modules abundant in places; slickensides common; soft to very stiff	Offshore lacustrine sediment	Late Wisconsinan
Brenna Transition	Clay, silty clay, some silt and sand; gray-dark gray, clay stringers; silt and pebble-loam inclusion increase toward the base; stiff to very stiff		
FALCONER FORMATION	Silty, clayey pebble loam; some sand and gravel beds; light gray; nonstratified	Glacial sediment	Late Wisconsinan
HUOT FORMATION	Slightly pebbly clay loam; gray-dark gray; nonstratified; slickensides common	Glacial sediment	Late Wisconsinan
WYLIE FORMATION	Clay and silt; olive gray-dark gray; laminated to unbedded; slickensides common	Offshore lacustrine sediment	Late Wisconsinan
POPLAR RIVER FORMATION West Fargo Member	Sand, silt, some gravel; yellowish brown-light gray, laminations common; crossbedding common, contains shell and wood fragments, peat, and dispersed organics	Fluvial channel and near-channel overbank sediment	Late Wisconsinan
Harwood Member	Clay and silty clay; dark grayish brown-dark gray; mottled; mealy structure; very stiff	Fluvial overbank sediment	
ARGUSVILLE FORMATION	Silty clay, clay, sand; gray-dark gray; unbedded; clay stringers; silt and pebble-loam inclusions; gritty appearance; stiff to very stiff	Offshore lacustrine sediment	Late Wisconsinan
UNIT A	Pebble loam; silty, gray-dark gray	Glacial sediment	Late Wisconsinan?
UNIT B	Pebble loam, sandy, gray-dark gray	Glacial sediment	Late Wisconsinan?
UNIT C	Clay, silty clay, clayey silt, silt; laminated to unbedded; silt and pebble-loam inclusions; stiff-very stiff	Offshore lacustrine sediment	Late Wisconsinan?
UNIT D	Pebble loam; silty; gray-dark gray	Glacial sediment	Late Wisconsinan?

29-77: North Dakota State Highway Department designation for structure number 77 on Interstate Highway 29.

Vertical scale: 1 inch=40 feet

Horizontal scale: 1 inch=2 miles

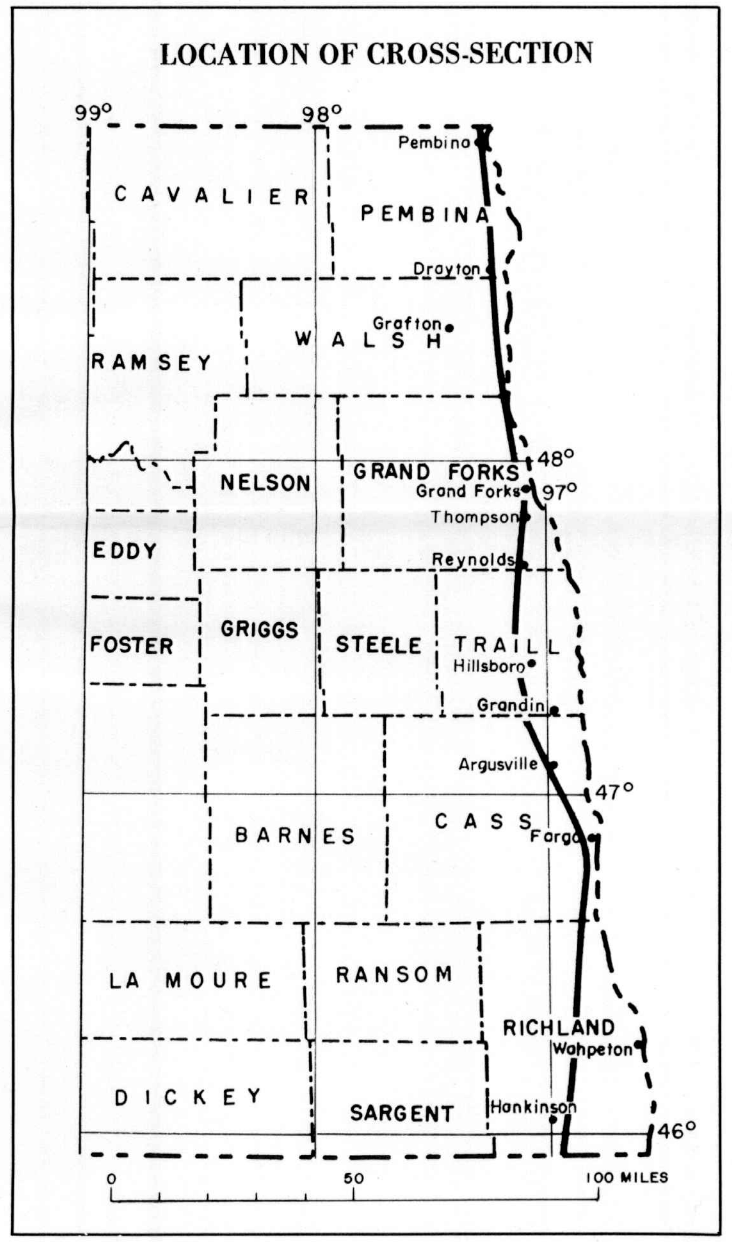
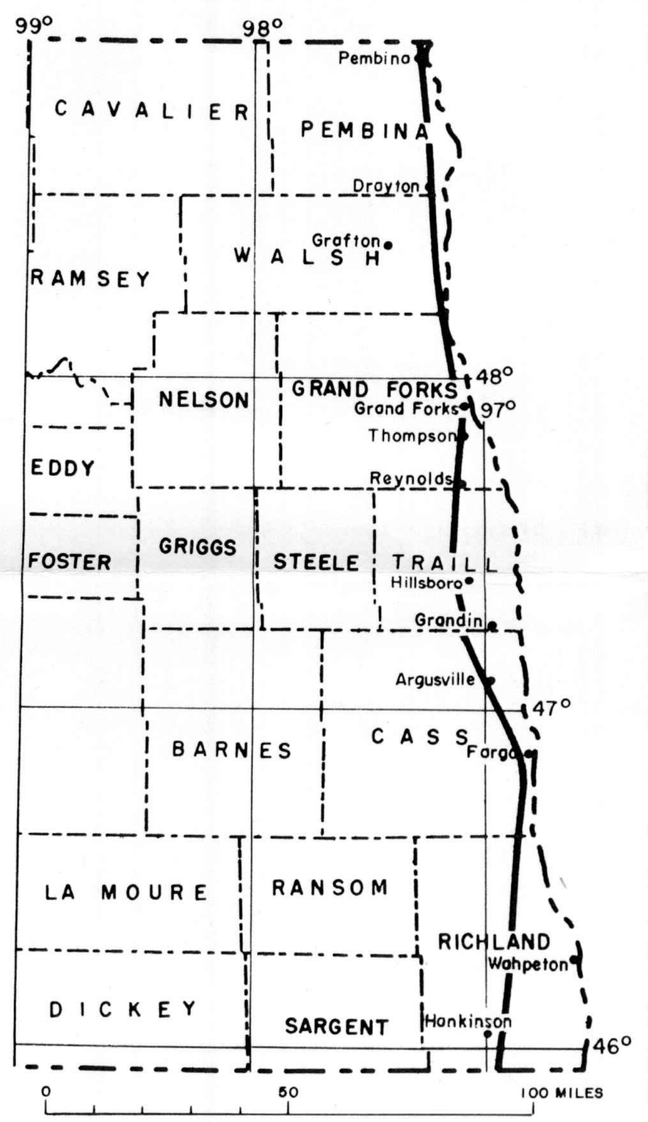


PLATE 2 CROSS SECTION SHOWING STRATIGRAPHY OF OFFSHORE SEDIMENT OF LAKE AGASSIZ IN THE RED RIVER VALLEY OF NORTH DAKOTA.

LOCATION OF CROSS-SECTION



EXPLANATION

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HUOT FORMATION	Slightly pebbly clay loam; gray-dark gray; nonstratified; slickensides common	Glacial sediment	Late Wisconsinan
WYLIE FORMATION	Clay and silt; olive gray-dark gray; laminated to unbedded; slickensides common	Offshore lacustrine sediment	Late Wisconsinan
POPLAR RIVER FORMATION West Fargo Member	Sand, silt, some gravel; yellowish brown-light gray, laminations common; crossbedding common, contains shell and wood fragments, peat, and dispersed organics	Fluvial channel and near-channel overbank sediment	Late Wisconsinan
Harwood Member	Clay and silty clay; dark grayish brown-dark gray; mottled; mealy structure; very stiff	Fluvial overbank sediment	
ARGUSVILLE FORMATION	Silty clay, clay, sand; gray-dark gray; unbedded; clay stringers; silt and pebble-loam inclusions; gritty appearance; stiff to very stiff	Offshore lacustrine sediment	Late Wisconsinan
UNIT A	Pebble loam; silty, gray-dark gray	Glacial sediment	Late Wisconsinan?
UNIT B	Pebble loam, sandy, gray-dark gray	Glacial sediment	Late Wisconsinan?
UNIT C	Clay, silty clay, clayey silt, silt; laminated to unbedded; silt and pebble-loam inclusions; stiff-very stiff	Offshore lacustrine sediment	Late Wisconsinan?
UNIT D	Pebble loam; silty; gray-dark gray	Glacial sediment	Late Wisconsinan?

29-77: North Dakota State Highway Department designation for structure number 77 on Interstate Highway 29.

Vertical scale: 1 inch=40 feet

Horizontal scale: 1 inch=2 miles

PLATE 3 ENGINEERING CHARACTERISTICS OF SELECTED STRATIGRAPHIC AND OTHER UNITS IN THE RED RIVER VALLEY OF NORTH DAKOTA.